Recent results from BESIII

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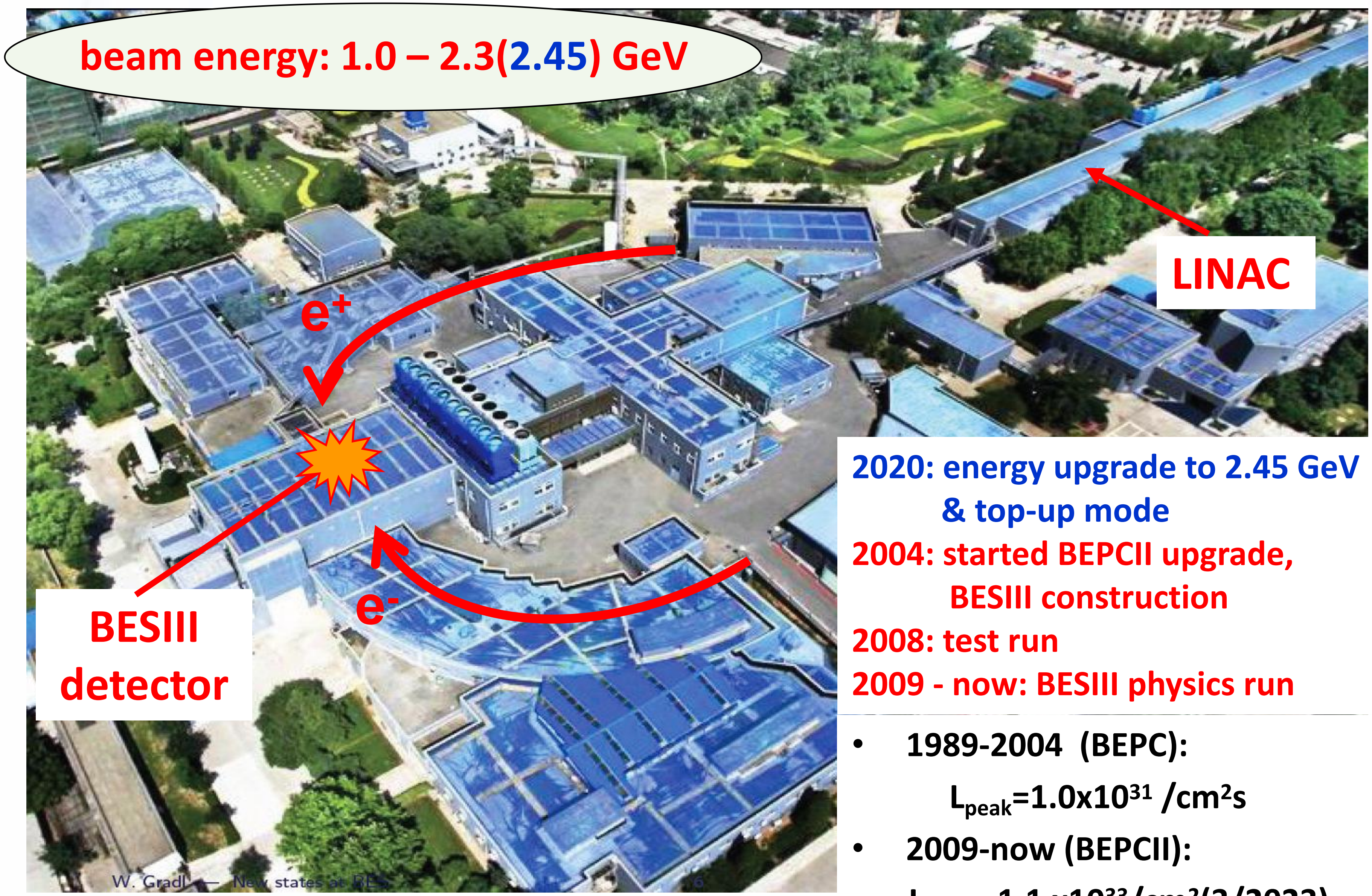
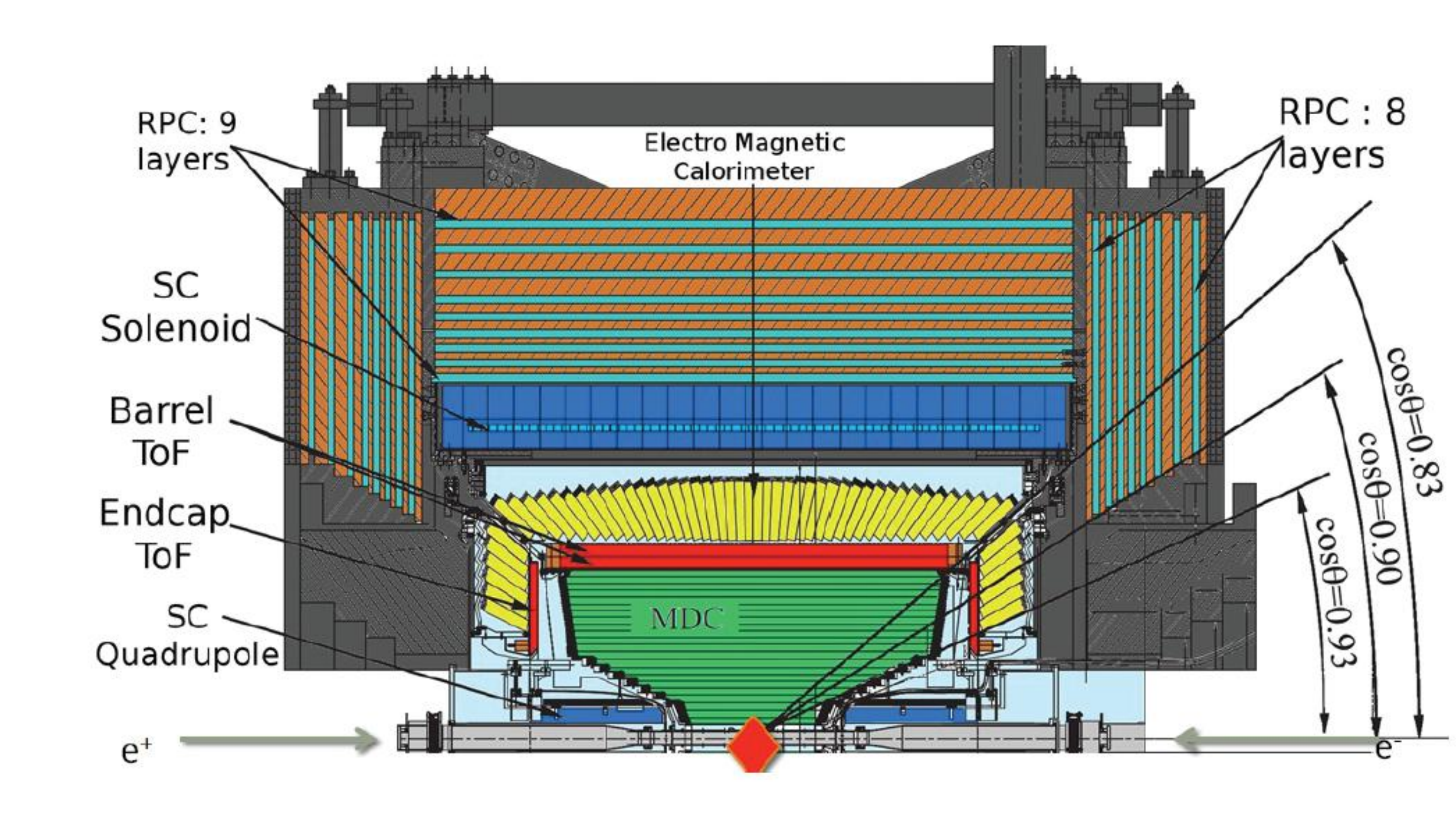
Beijing Electron Positron Collider II (BEPCII)



2020: energy upgrade to 2.45 GeV
& top-up mode
2004: started BEPCII upgrade,
BESIII construction
2008: test run
2009 - now: BESIII physics run

- 1989-2004 (BEPC):
  L_{peak}=1.0x10^{31} /cm^{2}s
- 2009-now (BEPCII):
  L_{peak}= 1.1 x10^{33}/cm^2(3/2023)

BESIII spectrometer

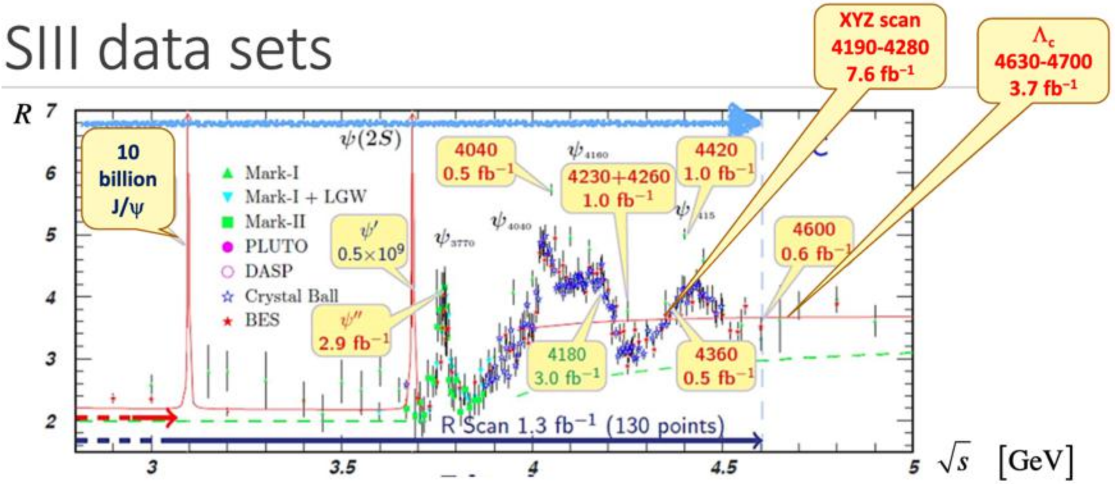


- **MDC:**
  - Material<$0.05X_0$, $\sigma_{xy} < 130\ \mu m$
  - $\sigma(p)/p < 0.5\%@1\ \mathrm{GeV}/c$
  - $\sigma_{dE/dx} < 6\%$
- **TOF:**
  - σ_t~70 ps (barreal two layers)
  - σ_t~110(60) ps (endcap)
- **EMC:**
  - $\sigma_E/\sqrt{E} < 2.5\%$ @ 1 GeV
  - $\sigma_x < 0.6$ cm
- **MUC**
  - No. of layers (barrel/endcap) 9/8
  - Cut-off momentum (MeV/c) 0.4

BESIII data sample

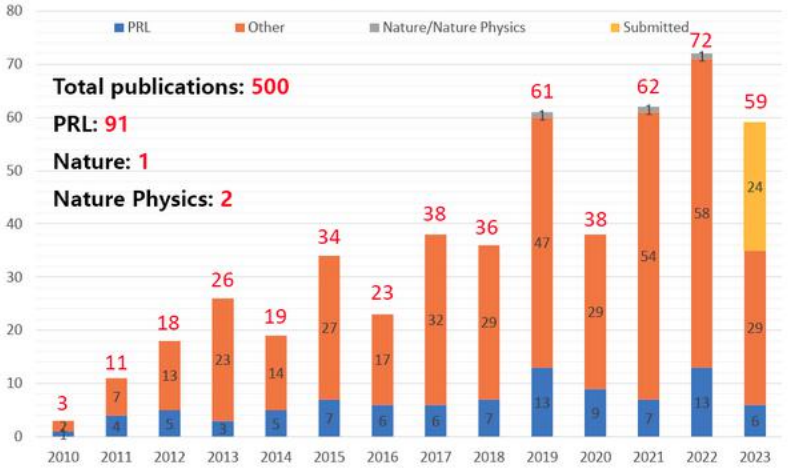
2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 pb^{-1} at $\psi(3770)$
2011: 2.9 fb^{-1} *(total)* at $\psi(3770)$
482 pb^{-1} at 4.01 GeV
2012: 0.45B *(total)* $\psi(2S)$
1.3B *(total)* J/ψ
2013: 1092 pb^{-1} at 4.23 GeV
826 pb^{-1} at 4.26 GeV
540 pb^{-1} at 4.36 GeV
10×50 pb^{-1} scan 3.81 — 4.42 GeV
2014: 1029 pb^{-1} at 4.42 GeV
110 pb^{-1} at 4.47 GeV
110 pb^{-1} at 4.53 GeV
48 pb^{-1} at 4.575 GeV
567 pb^{-1} at 4.6 GeV
0.8 fb^{-1} R-scan 3.85 — 4.59 GeV
2015: R-scan 2 — 3 GeV + 2.175 GeV
2016: ~3fb^{-1} at 4.18 GeV (for D_s)
2017: 7×500 pb^{-1} scan 4.19 — 4.27 GeV
2018: more J/ψ *(and tuning new RF cavity)*
2019: 10B *(total)* J/ψ
8×500 pb^{-1} scan 4.13, 4.16, 4.29 — 4.44 GeV
2020: 3.8 fb^{-1} scan **4.61-4.7 GeV**
2021: 2 fb^{-1} scan **4.74-4.95 GeV**; 2.55B $\psi(2S)$
2022: 5.1 fb^{-1} at $\psi(3770)$
2023: ~8 fb^{-1} will be taken at $\psi(3770)$

Many topics!
spectroscopy (light and heavy), flavor physics, new physics, R scans, τ physics, etc.

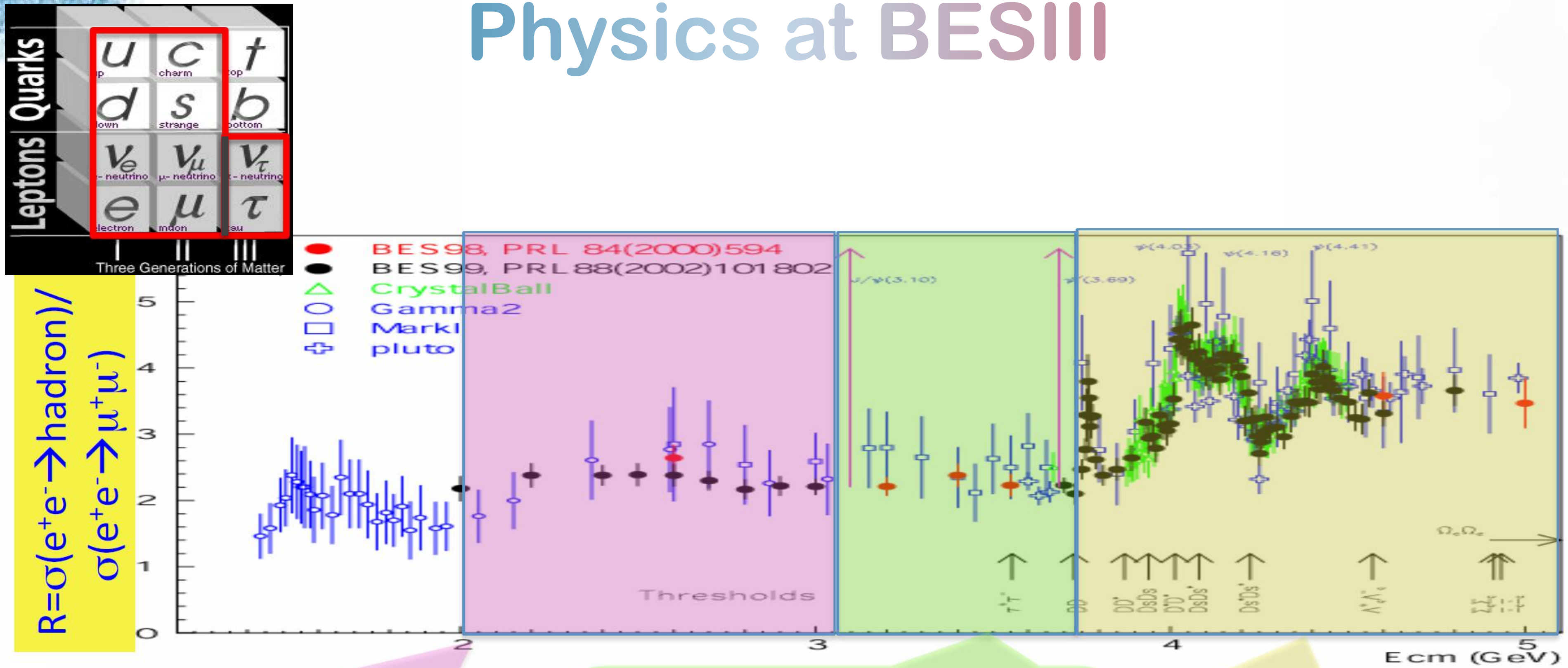


BESIII publications (May 9, 2023)

500 publications!



Physics at BESIII



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

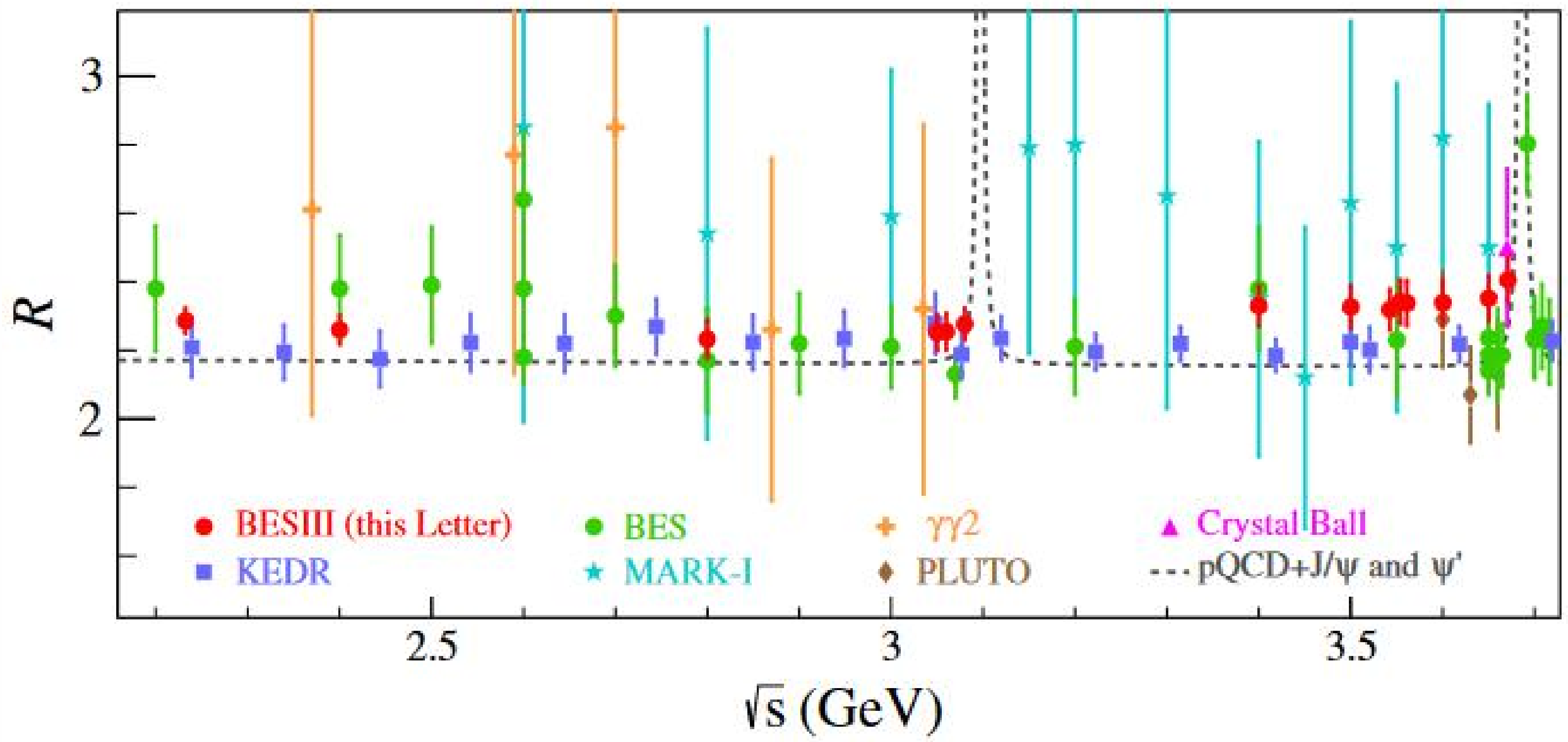
- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- D mesons
- f_D and f_{Ds}
- D_0-$\bar{D}_0$ mixing
- Charm baryons

R value at BESIII

Phys.Rev.Lett. 128 (2022) 6, 062004

- 14 fine-scan data points from 2.23-3.67 GeV
- The accuracy is better than 2.6% below 3.1 GeV and 3.0% above
- Larger than the pQCD prediction by 2.7σ between 3.4-3.6 GeV
- Important input for the SM-prediction of g-2



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Helicity amplitude analysis of $\chi_{cJ} \to \phi\phi$

- Predictions are smaller than measured branching fraction [Phys. Lett. B 93 (1980) 119, Phys. Lett. B 93 (1980) 119, Phys. Lett. B 93 (1980) 119]
- BESIII measured $\chi_{cJ} \to \phi\phi$ before without amplitude analysis [Phys.Rev.Lett. 107 (2011) 092001]
- The analysis of the ϕ meson polarization: probe hadronic-loop effects in the $\chi_{cJ} \to \phi\phi$ decay [Phys. Lett. B 93 (1980) 119]
- The ratios of the helicity amplitudes are effective in the discrimination between the proposed models [Phys. Lett. B 611 (2005) 123, Phys. Lett. B 611 (2005) 123, Phys. Lett. B 93 (1980) 119]

Table 1. Numerical results of predictions from pQCD [6], $^3P_0$ [9] and $D\bar{D}$ loop models [10].

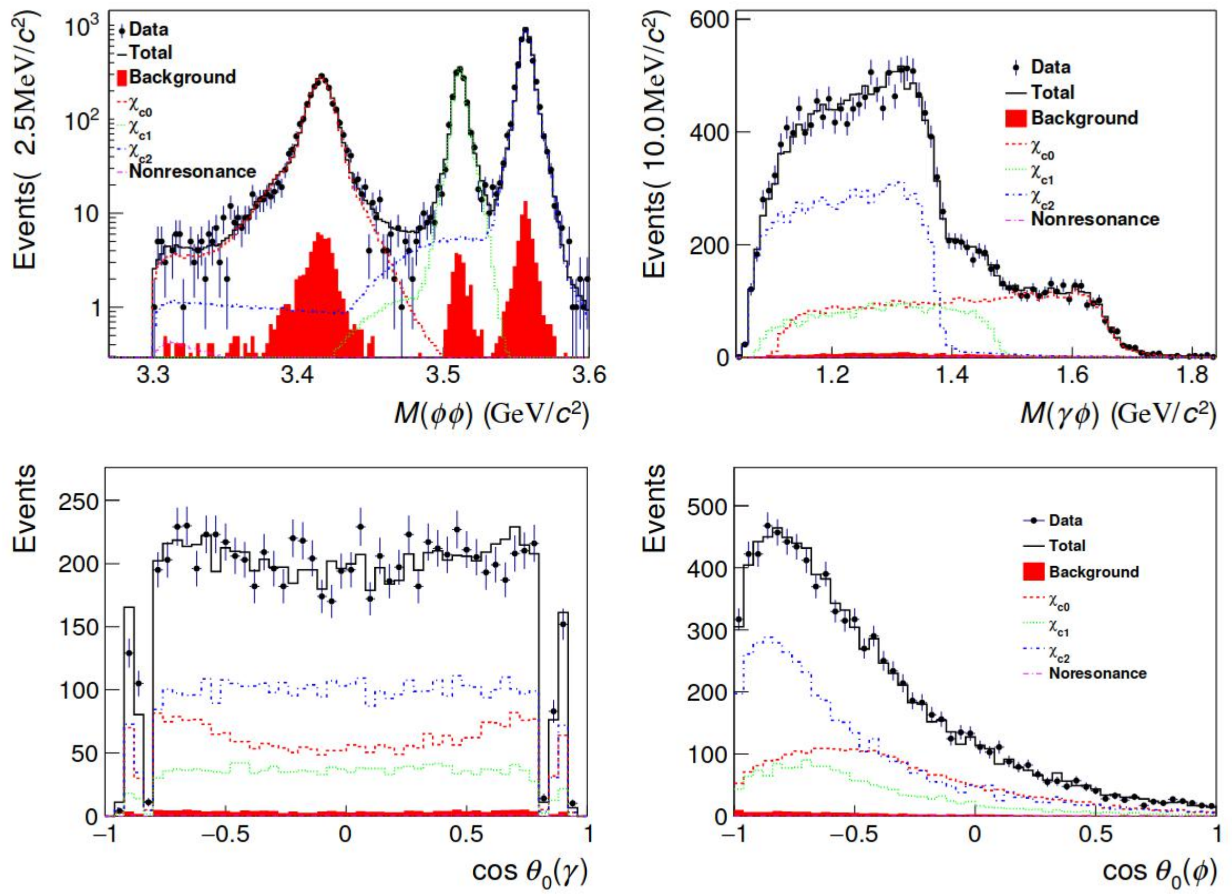
Decay channel	$\chi_{c0} \to \phi\phi$	$\chi_{c2} \to \phi\phi$		
Parameter	x	ω_1	ω_2	ω_4
pQCD	0.293 ± 0.030	0.812 ± 0.018	1.647 ± 0.067	0.344 ± 0.020
$^3P_0$	0.515 ± 0.029	1.399 ± 0.580	0.971 ± 0.275	0.406 ± 0.017
$D\bar{D}$ loop	0.359 ± 0.019	1.285 ± 0.017	5.110 ± 0.057	0.465 ± 0.002

- $x = |F^0_{1,1}/F^0_{0,0}|$ for χ_{c0}
- $\omega_1 = |F^2_{0,1}/F^2_{0,0}|$, $\omega_2 = |F^2_{1,-1}/F^2_{0,0}|$, $\omega_4 = |F^2_{1,1}/F^2_{0,0}|$ for χ_{c2} ($F^{J=0,2}_{\lambda_1,\lambda_2}$ are the helicity amplitudes)

Helicity amplitude analysis of $\chi_{cJ} \to \phi\phi$

- Properties of χ_{c0}:
  - $m_{\chi_{c0}} = 3415.42\ \mathrm{MeV}/c^2$
  - $\Gamma_{\chi_{c0}} = 11.4\ \mathrm{MeV}/c^2$
- For χ_{c0}:
  - $x = |F^0_{1,1}/F^0_{0,0}| = 0.299 \pm 0.003 \pm 0.019$
- For χ_{c1} (statistical uncertainty only):
  - $u_1 = |F^1_{1,0}/F^1_{0,1}| = 1.05 \pm 0.05$
  - $u_2 = |F^1_{1,1}/F^1_{1,0}| = 0.07 \pm 0.04$
- For χ_{c2}:
  - $\omega_1 = |F^2_{0,1}/F^2_{0,0}| = 1.265 \pm 0.054 \pm 0.079$
  - $\omega_2 = |F^2_{1,-1}/F^2_{0,0}| = 1.450 \pm 0.097 \pm 0.104$
  - $\omega_4 = |F^2_{1,1}/F^2_{0,0}| = 0.808 \pm 0.051 \pm 0.009$
- Branching fractions
  - $B(\chi_{c0} \to \phi\phi) = (8.59 \pm 0.27 \pm 0.20) \times 10^{-4}$
  - $B(\chi_{c1} \to \phi\phi) = (4.26 \pm 0.13 \pm 0.15) \times 10^{-4}$
  - $B(\chi_{c2} \to \phi\phi) = (12.67 \pm 0.28 \pm 0.33) \times 10^{-4}$

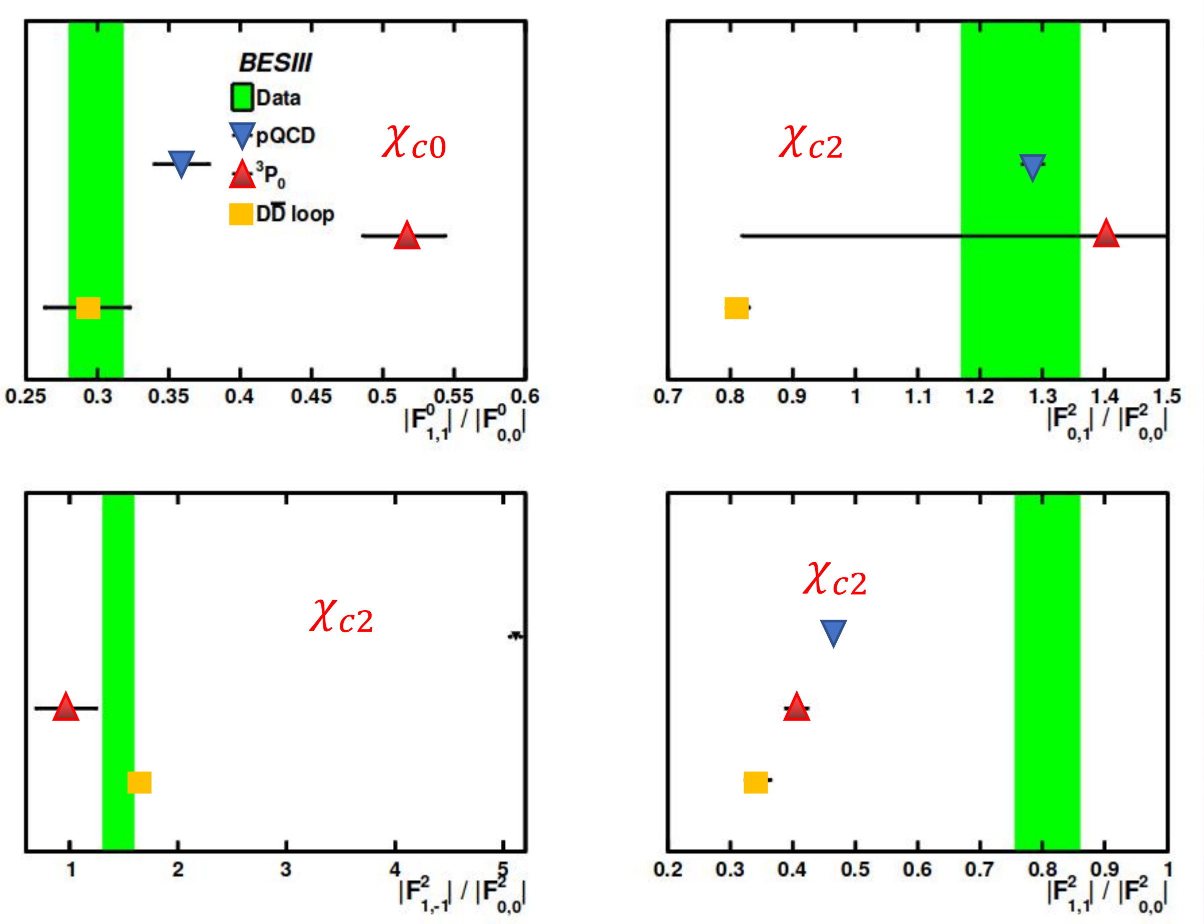
JHEP 05, 069 (2023)



Helicity amplitude analysis of $\chi_{cJ} \to \phi\phi$

- Discussions:
  - For the decay of χ_{c1}, no evidence of identical particle symmetry breaking
  - For the deday of χ_{c0}, consistent with the pQCD prediction
  - For the decay of χ_{c2}, the $D\bar{D}$ loop model ruled out due to the large deviation, while the other models cannot describe the measurements, either.

  - Using about 2.7 billion $\psi(3686)$ accumulated at BESIII now, more attractive results will be reported in future

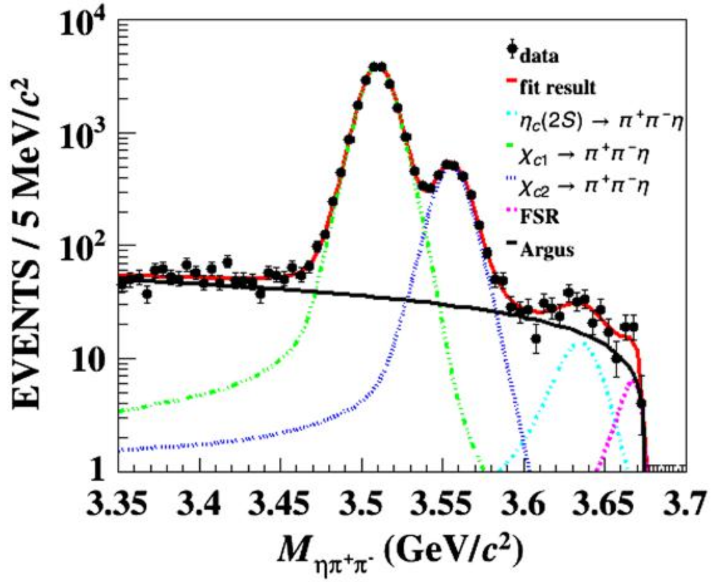


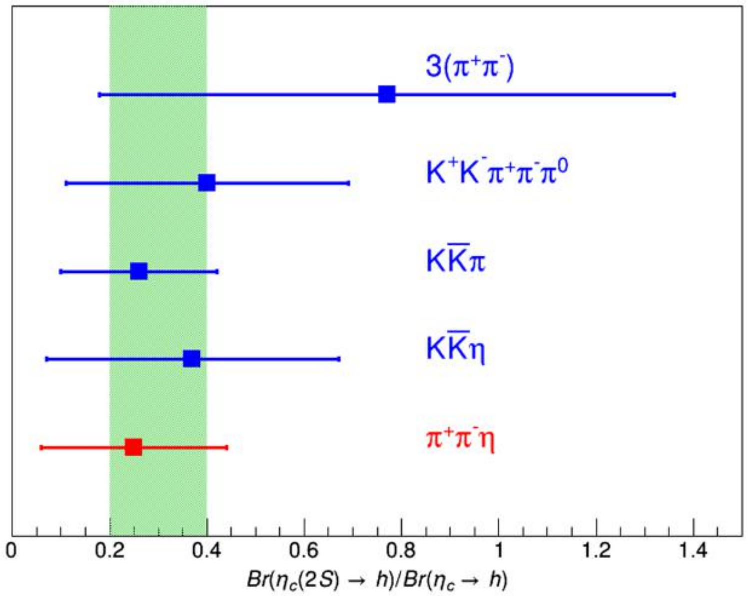
Evidence for the $\eta_c(2S) \to \pi^+\pi^-\eta$

- With the branching fraction $Br(\eta_c \to \pi^+\pi^-\eta) = (1.7 \pm 0.5)\%$, the ratio of the branching fractions of η_c and $\eta_c(2S)$ decaying into $\pi^+\pi^-\eta$ is calculated to be

$$\frac{Br(\eta_c(2S)\to\pi^+\pi^-\eta)}{Br(\eta_c\to\pi^+\pi^-\eta)} = 0.25 \pm 0.20$$

- Combining other hadronic decays, the average ratio is determined to be 0.30 ± 0.10
- Using the 2.7 billion $\psi(3686)$ events collected at BESIII, more precise results will be reported





Phys.Rev.D 107 (2023) 5, 052007

Observation of $\psi(3770) \to \eta J/\psi$

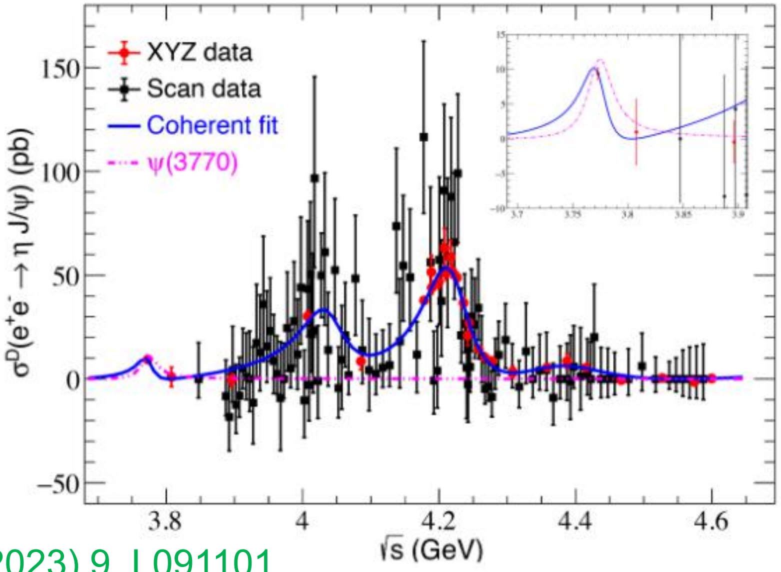
- Two treatments of the $\psi(3770)$ resonant decay amplitude is considered:
  - ✓ $\psi(3770)$ is coherent with the other amplitudes:

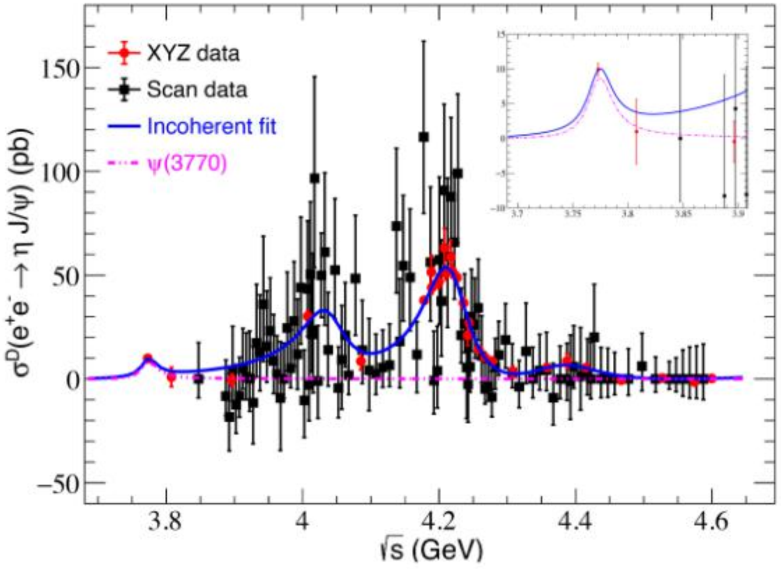
$$\sigma_{co.} = |C \cdot \sqrt{\Phi(s)} + e^{i\phi_1}\mathrm{BW}_{\psi(3770)} + e^{i\phi_2}\mathrm{BW}_{\psi(4040)} + e^{i\phi_3}\mathrm{BW}_{Y(4230)} + e^{i\phi_4}\mathrm{BW}_{Y(4390)}|^2$$

  - ✓ $\psi(3770)$ is incoherent with the other amplitudes:

$$\sigma_{co.} = |\mathrm{BW}_{\psi(3770)}|^2 + |C \cdot \sqrt{\Phi(s)} + e^{i\phi_2}\mathrm{BW}_{\psi(4040)} + e^{i\phi_3}\mathrm{BW}_{Y(4230)} + e^{i\phi_4}\mathrm{BW}_{Y(4390)}|^2$$

- **Incoherent**: $Br(\psi(3770) \to \eta J/\psi) = (8.7 \pm 1.0_{\mathrm{stat}} \pm 1.0_{\mathrm{sys}}) \times 10^{-4}$, close to the result of CLEO
- **Coherent:** Four solutions with branching fraction varying between $Br(\psi(3770) \to \eta J/\psi) = (11.2 \pm 5.8_{\mathrm{stat}} \pm 1.1_{\mathrm{sys}}) \times 10^{-4}$ and $(11.6 \pm 6.0_{\mathrm{stat}} \pm 1.1_{\mathrm{sys}}) \times 10^{-4}$ (substantial interference effect with highly excited vector states)





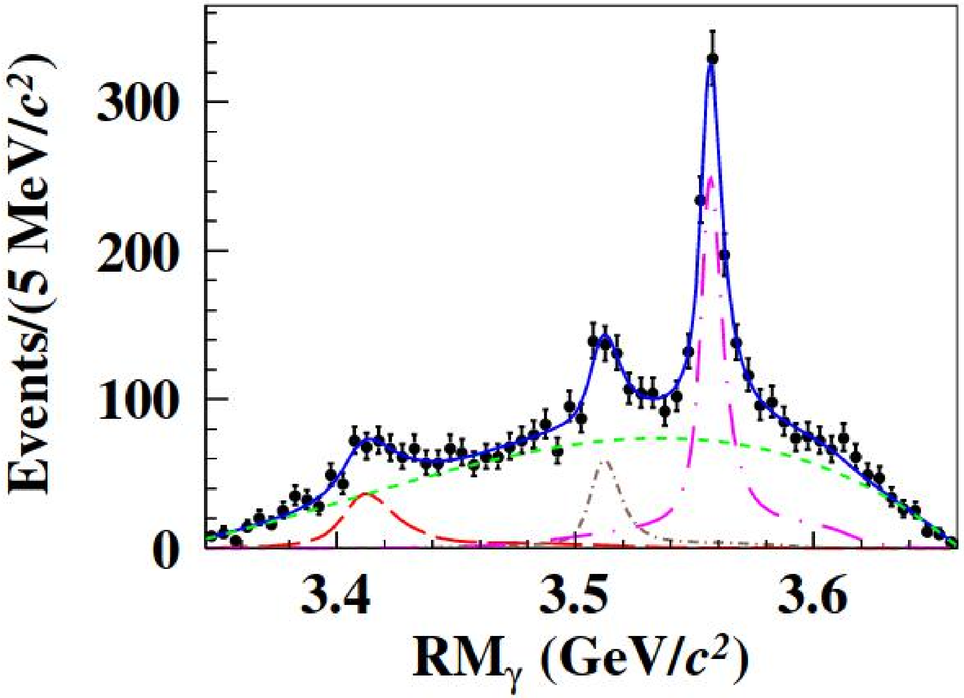
Phys.Rev.D 107 (2023) 9, L091101

Observation of the decay $\chi_{cJ} \to \Omega\bar{\Omega}$

- Signal yield is obtained by an unbinned maximum likelihood fit to the recoil mass spectrum of the radiative photon (RM_γ)
- $Br(\chi_{cJ} \to \Omega^-\bar{\Omega}^+) = \frac{N^{\text{obs}}_{\chi_{cJ}}}{N_{\psi(3686)} \cdot Br(\psi(3686) \to \gamma\chi_{cJ}) \cdot \varepsilon}$

Phys.Rev.D 107 (2023) 9, 092004

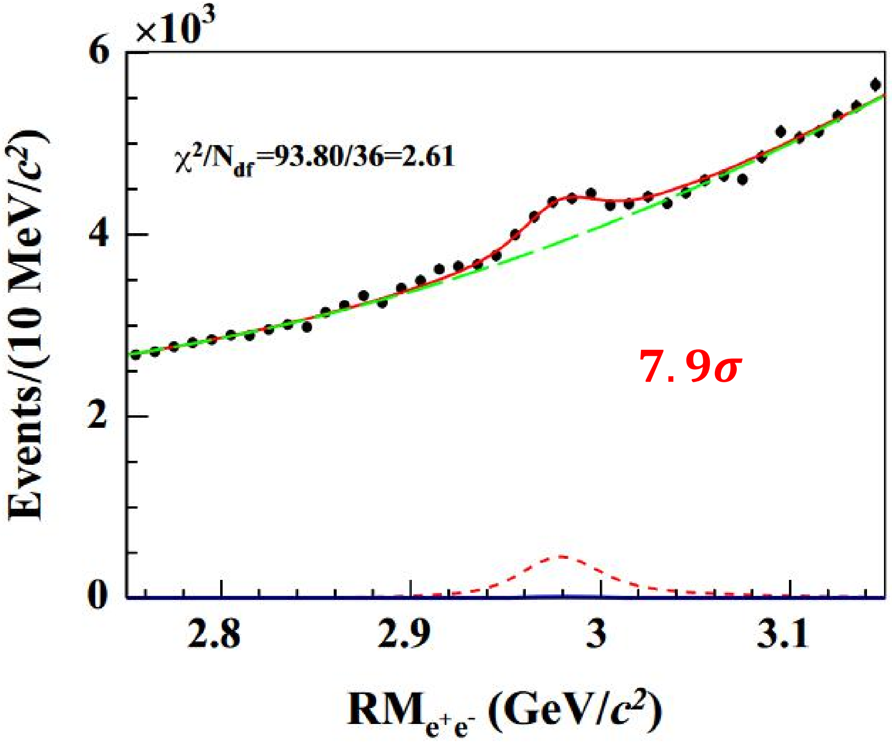
Mode	$N^{\text{obs}}_{\chi_{cJ}}$	$\epsilon_{\chi_{cJ}}(\%)$	Sig.(σ)	$\mathcal{B}(\times 10^{-5})$
χ_{c0}	284 ± 44	3.05	5.6	3.51 ± 0.54
χ_{c1}	277 ± 42	7.02	6.4	1.49 ± 0.23
χ_{c2}	1038 ± 56	8.91	18	4.52 ± 0.24

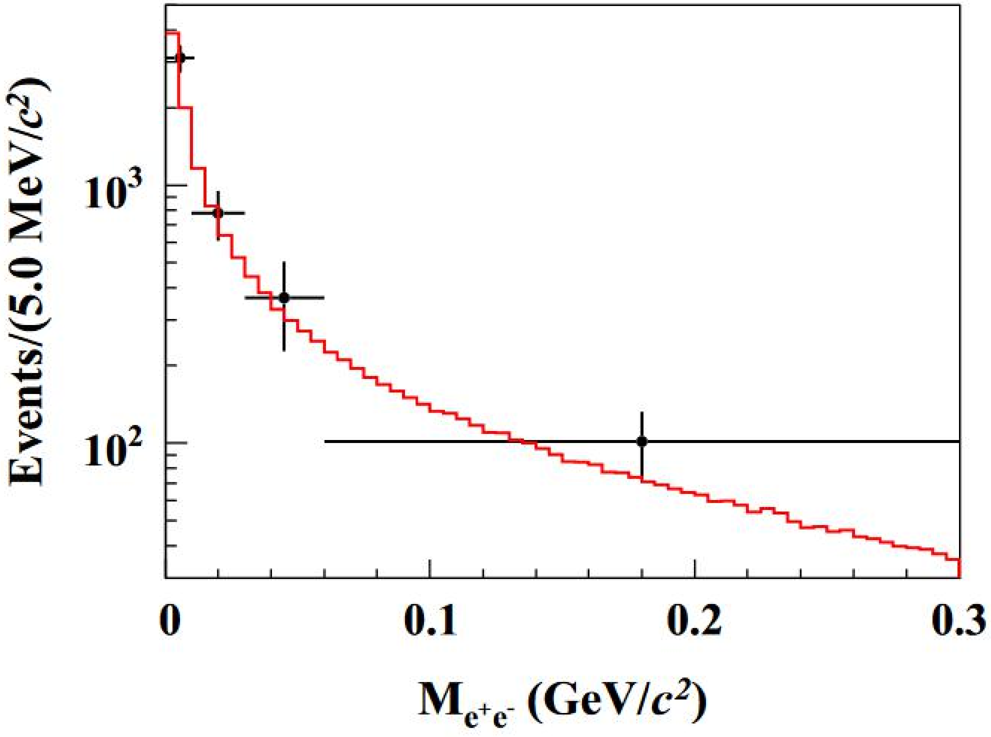


Observation of the decay $\psi(3686) \to e^+e^-\eta_c$

- Only e^+e^- pairs reconstructed. Signal yield obtained by fitting recoil mass of e^+e^-
- $Br(\psi(3686) \to e^+e^-\eta_c) = (3.77 \pm 0.40_{\text{stat.}} \pm 0.18_{\text{syst.}}) \times 10^{-5}$
- $\frac{Br(\psi(3686)\to e^+e^-\eta_c)}{Br(\psi(3686)\to \gamma\eta_c)} = (1.11 \pm 0.21) \times 10^{-2}$

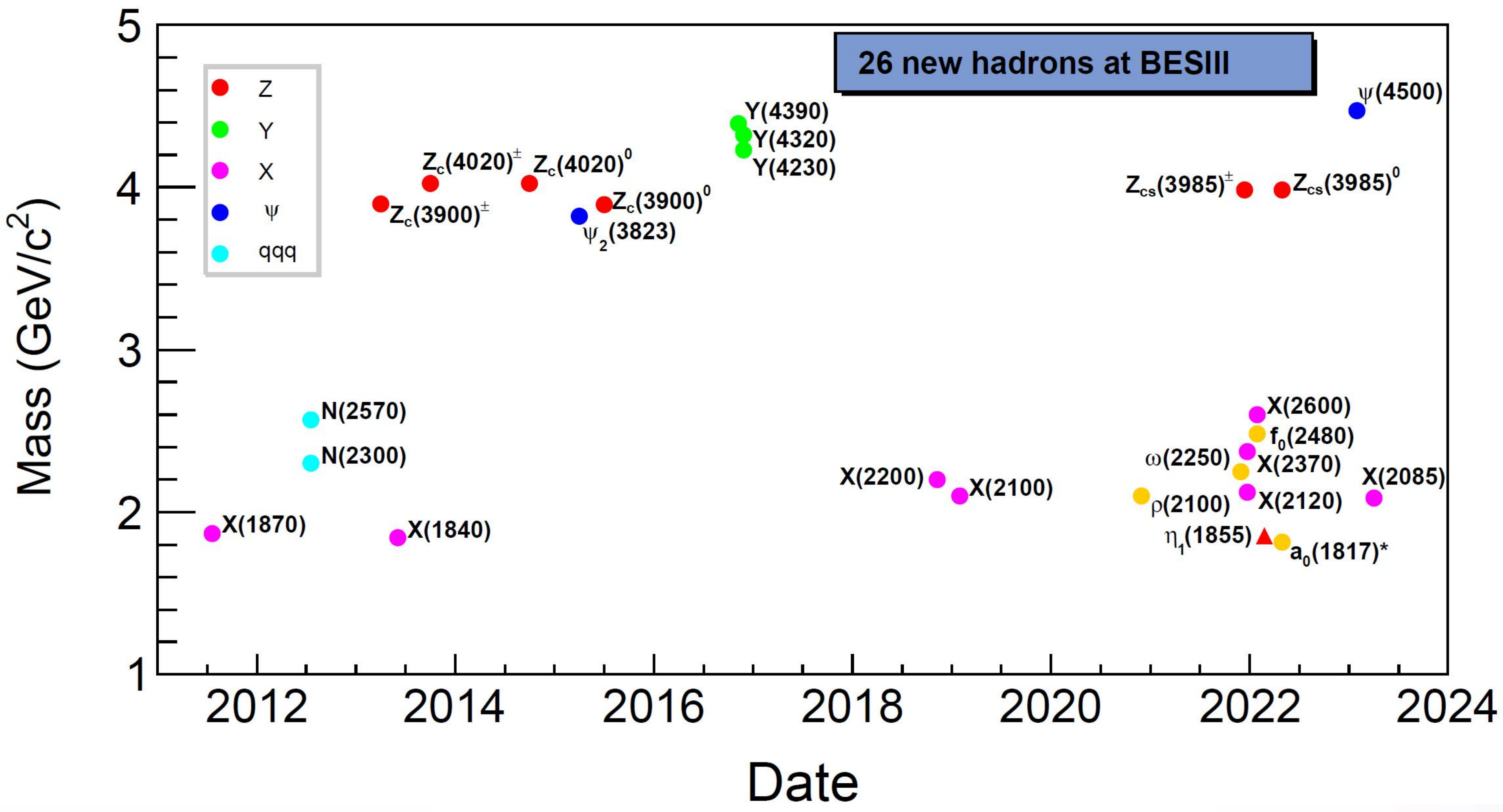
Phys.Rev.D 106 (2022) 112002





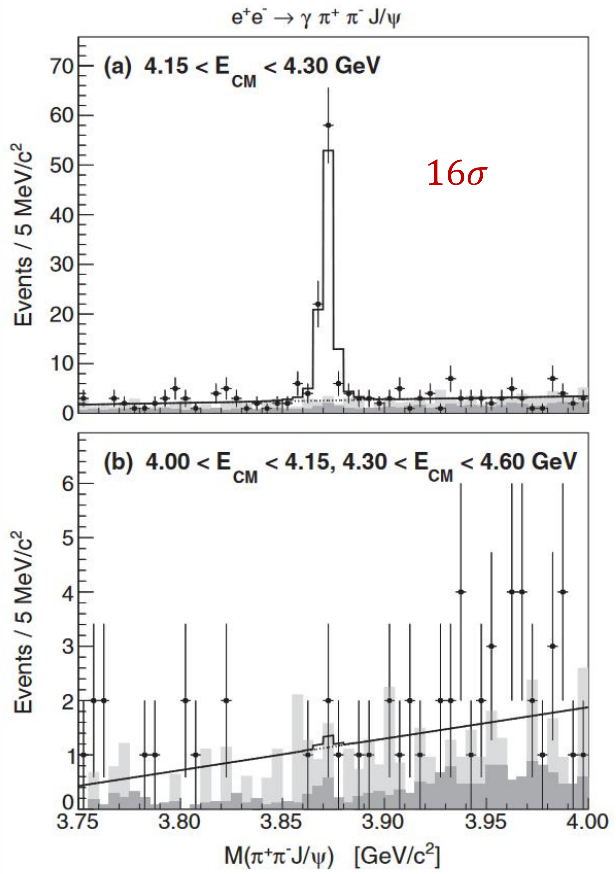
Content

New states at BESIII



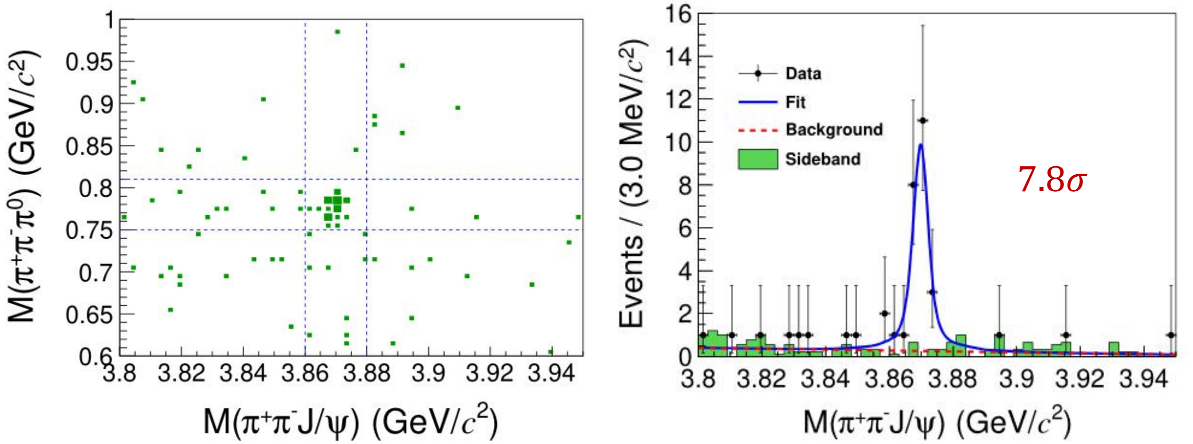
A new X(3872) production process $e^+e^- \to \omega X(3872)$

Phys.Rev.Lett. 122 (2019) 20, 202001



radiative production via $e^+e^- \to \gamma X(3872)$

Phys.Rev.Lett. 130 (2023) 15, 151904

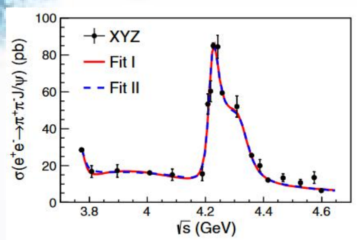


- A new X(3872) production process $e^+e^- \to \omega X(3872)$ is observed for the first time
- $M_{X(3872)} = 3870.2 \pm 0.7 \pm 0.3\ \mathrm{MeV}/c^2$
- The line shape of the cross section indicates that the observed $\omega X(3872)$ signals may be from decays of some nontrivial structures.

$\sqrt{s}$ (GeV)	$\mathcal{L}_{\rm int}(\mathrm{pb}^{-1})$	$N_{\rm sig}$	$\epsilon(1+\delta)$ (%)	$\sigma^B(pb)$	$\sigma^B_{\rm up}(pb)$	Significance
4.661	529.63	$0.33^{+1.36}_{-0.33}$	28.3	$0.5^{+2.1}_{-0.5} \pm 0.1 \pm 0.2$	5.6	$\cdots$
4.682	1669.31	$8.00^{+3.34}_{-2.68}$	24.6	$4.6^{+1.9}_{-1.5} \pm 0.4 \pm 1.5$	11.5	3.4σ
4.699	536.45	$0.00^{+0.95}_{-0.00}$	27.0	$0.0^{+1.6}_{-0.0} \pm 0.0 \pm 0.0$	3.3	$\cdots$
4.740	164.27	$1.67^{+1.77}_{-1.10}$	21.8	$10.9^{+11.6}_{-7.2} \pm 1.0 \pm 3.5$	40.6	1.0σ
4.750	367.21	$5.00^{+2.58}_{-1.92}$	22.4	$14.2^{+7.4}_{-5.5} \pm 1.4 \pm 4.5$	38.2	3.1σ
4.781	512.78	$1.00^{+1.36}_{-0.70}$	31.6	$1.5^{+2.0}_{-1.0} \pm 0.2 \pm 0.5$	6.5	0.7σ
4.843	527.29	$4.67^{+2.58}_{-1.92}$	26.7	$7.8^{+4.3}_{-3.2} \pm 0.7 \pm 2.5$	21.1	2.6σ
4.918	208.11	$1.00^{+1.36}_{-0.70}$	22.6	$5.0^{+6.8}_{-3.5} \pm 0.4 \pm 1.6$	21.7	0.7σ
4.951	160.37	$0.00^{+0.95}_{-0.00}$	20.4	$0.0^{+6.8}_{-0.0} \pm 0.0 \pm 0.0$	14.7	$\cdots$

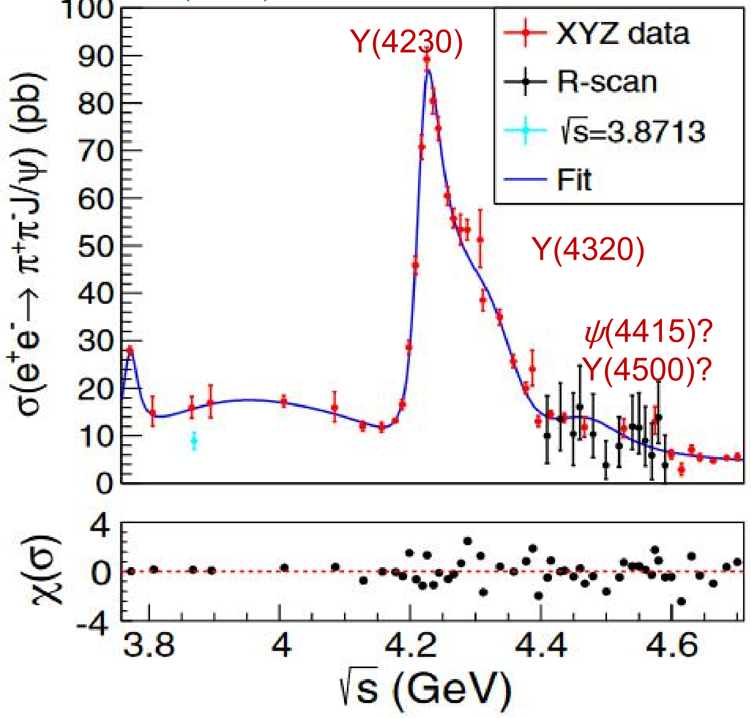
Cross section of $e^+e^- \to \pi^+\pi^- J/\psi$

Phys.Rev.Lett. 118 (2017) 9, 092001



higher statistics, higher percision, higher energies, better fit

Phys.Rev.D 106 (2022) 7, 072001



- Y(4230) and Y(4320) observed with > 10σ
- Structure around 4 GeV can be fitted better by a BW (an expotential function is used before)
- Evidence $\sim 3\sigma$ of a structure at higher energies ($\psi(4415)$? Y(4500)?)
- Taking higher states in the fit, the parameters of Y(4320) changed

$M_{Y(4230)} = 4221.4 \pm 1.5 \pm 2.0$ MeV/c^2
$\Gamma_{Y(4230)} = 41.8 \pm 2.9 \pm 2.7$MeV

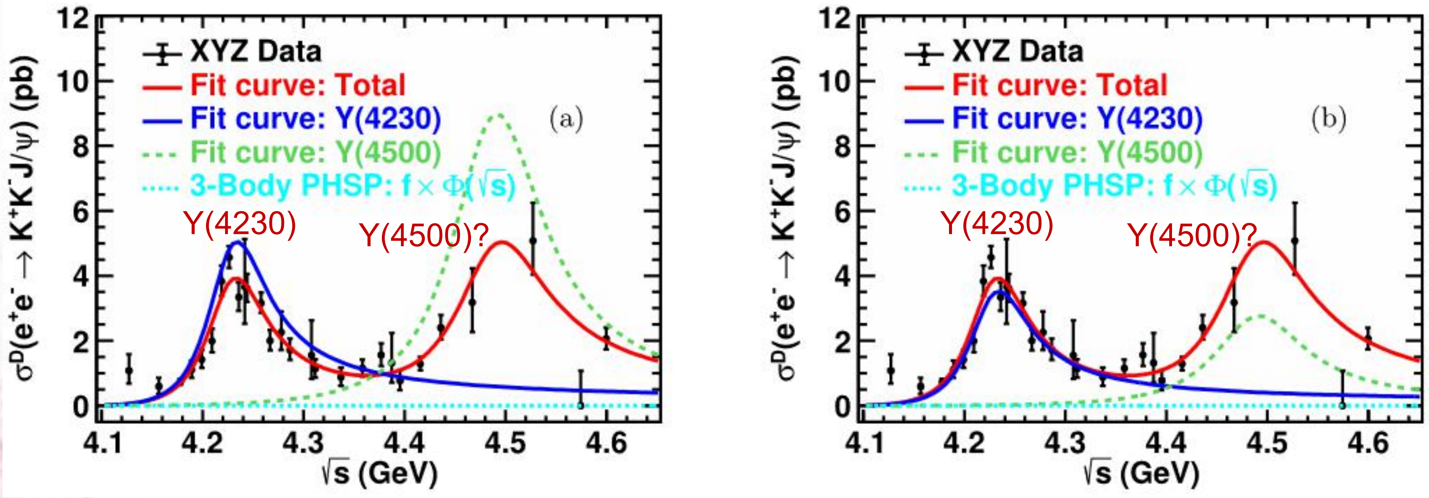
$M_{Y(4320)} = 4298 \pm 12 \pm 26$ MeV/c^2
$\Gamma_{Y(4320)} = 127 \pm 17 \pm 10$ MeV

Cross section of $e^+e^- \rightarrow K^+K^-J/\psi$

- Try to investigate the strange content inside Y(4230) [Phys.Rev.D 105 (2022) 3, L031506]
- First observation of $Y(4230) \rightarrow K^+K^-J/\psi$

$$0.02 < \frac{Br(Y(4230) \rightarrow K^+K^-J/\psi)}{Br(Y(4230) \rightarrow \pi^+\pi^-J/\psi)} < 0.26$$

- Resonance Y(4500)>5σ, the parameters are consistent with
  - ✓ 5S-4D mixing scheme [Phys.Rev.D 99 (2019) 11, 114003]
  - ✓ heavy-antiheavy hadronic molecules model [Progr.Phys. 41 (2021) 65-93]
  - ✓ Lattice QCD result for a $(cs\bar{c}\bar{s})$ state [Phys.Rev.D 73 (2006) 094510]

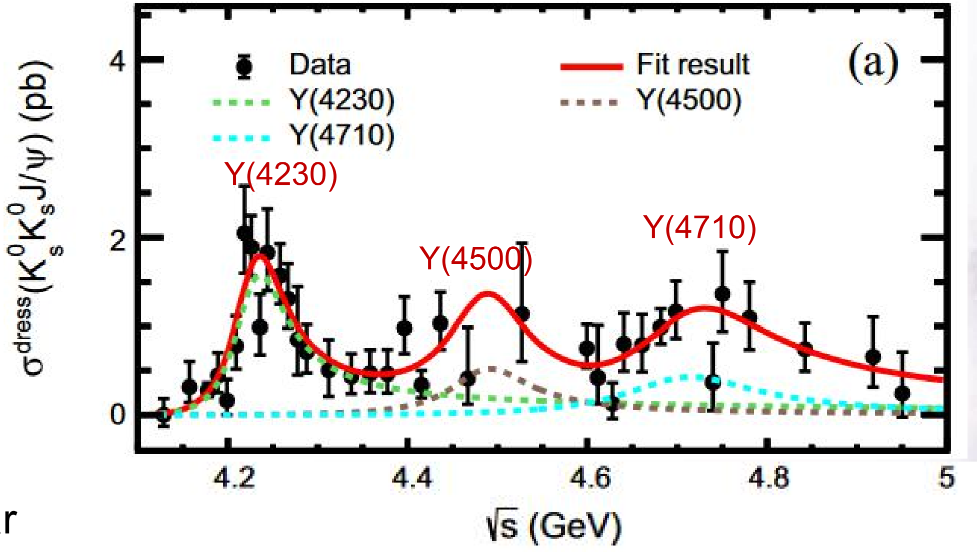


	Parameters	Solution I	Solution II
$Y(4230)$	M/MeV	$4225.3 \pm 2.3 \pm 21.5$	
	Γ_{tot}/MeV	$72.9 \pm 6.1 \pm 30.8$	
	$\Gamma_{ee}\mathcal{B}$/eV	$0.42 \pm 0.04 \pm 0.15$	$0.29 \pm 0.02 \pm 0.10$
$Y(4500)$	M/MeV	$4484.7 \pm 13.3 \pm 24.1$	
	Γ_{tot}/MeV	$111.1 \pm 30.1 \pm 15.2$	
	$\Gamma_{ee}\mathcal{B}$/eV	$1.35 \pm 0.14 \pm 0.07$	$0.41 \pm 0.08 \pm 0.13$
Phase angle	φ/rad	$1.72 \pm 0.09 \pm 0.52$	$5.49 \pm 0.35 \pm 0.58$

Chin.Phys.C 46 (2022) 11, 111002

Cross section of $e^+e^- \to K_S K_S J/\psi$

Resonance	Significance	Mass (MeV/c²)	Width (MeV/c²)
Y(4230)	26σ	$4226.9 \pm 6.6 \pm 22.0$	$71.7 \pm 16.2 \pm 32.8$
Y(4500)	$< 1.4\sigma$	not clear due to low statistics	
Y(4710)	26σ	$4704.0 \pm 52.3 \pm 69.5$	$183.2 \pm 114.0 \pm 96.1$



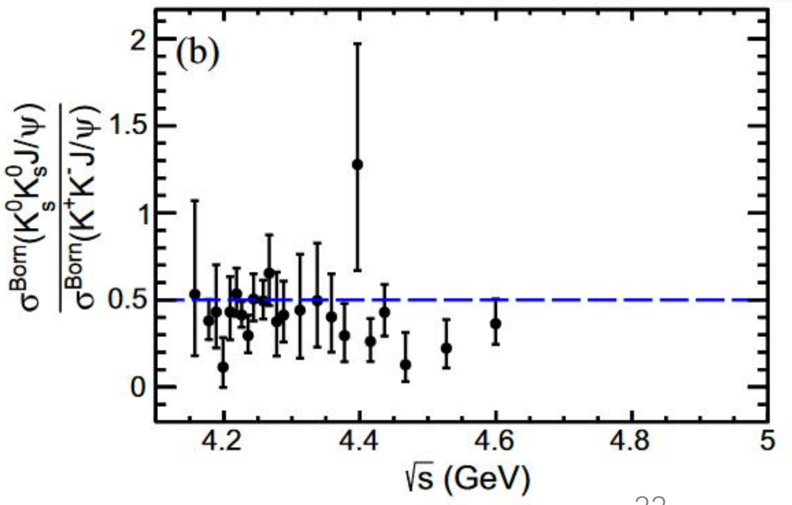
Phys.Rev.D 107 (2023) 9, 092005

- If assuming Y(4710) as $\psi(5S)$, the measured mass will be in favor of the linear potential model predictions [Phys.Rev.D 98 (2018) 1, 016010]
- Assymetric Gaussian fit (3.1σ hint for isospin violation):

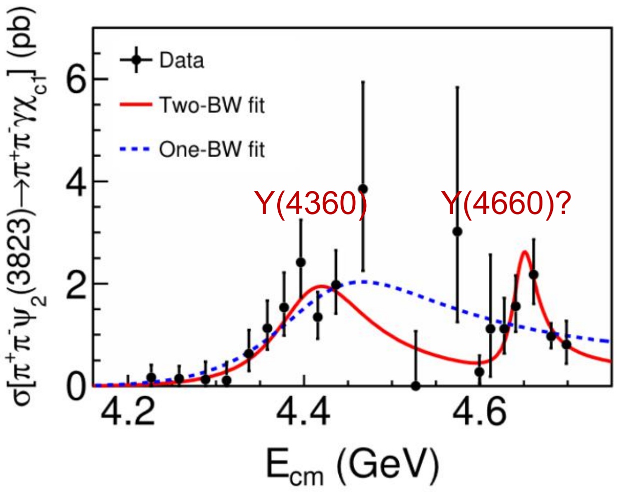
$$\frac{\sigma^{\mathrm{BORN}}(e^+e^- \to K_S K_S J/\psi)}{\sigma^{\mathrm{BORN}}(e^+e^- \to K^+K^- J/\psi)} = 0.338^{+0.035}_{-0.028}$$

- With considering the three-body phase space (1.9σ hint for isospin violation):

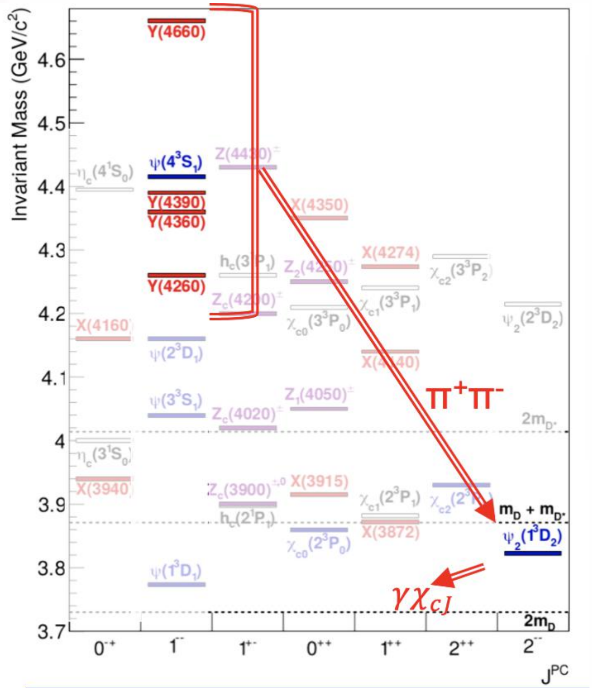
$$\frac{\sigma^{\mathrm{BORN}}(e^+e^- \to K_S K_S J/\psi)}{\sigma^{\mathrm{BORN}}(e^+e^- \to K^+K^- J/\psi)} = 0.426^{+0.038}_{-0.031} \pm 0.018$$



Cross section of $e^+e^- \to \pi^+\pi^-\psi_2(3823)$



Phys.Rev.Lett. 129 (2022) 10, 102003



- Most precise measurement of the parameters of $\psi_2(3823)$:

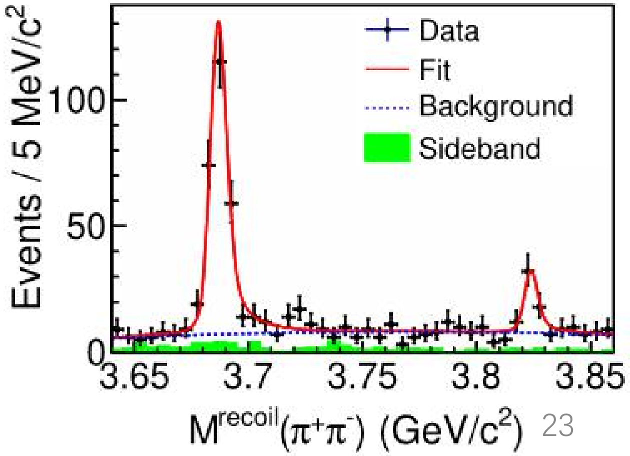
$$M = 3823.12 \pm 0.43 \pm 0.13\ \text{MeV}/c^2$$
$$\Gamma < 2.9\ \text{MeV (at 90\% CL)}$$

- First observation of vector Y states decaying into D-wave charmonium state
- Taking $\sigma(Y(4660) \to \pi^+\pi^-\psi(3686))$ measured by BESIII [Phys.Rev.D 104 (2021) 5, 052012]

$$\frac{\Gamma(Y(4660) \to \pi^+\pi^-\psi_2(3823))}{\Gamma(Y(4660) \to \pi^+\pi^-\psi(3686))} \sim 20\%$$

- Conflict with
- $f_0(980)\psi(3686)$ hadron molecule interpretation [Phys.Lett.B 665 (2008) 26-29]
- baryonium picture that explain Y(4660) as a baryonium of $\Sigma^0\bar{\Sigma}^0$ [J.Phys.G 35 (2008) 075008]
- diquark-antidiquark tetraquark explanation that explain Y(4660) as a radial excitation of Y(4260) [Phys.Rev.D 89 (2014) 114010]

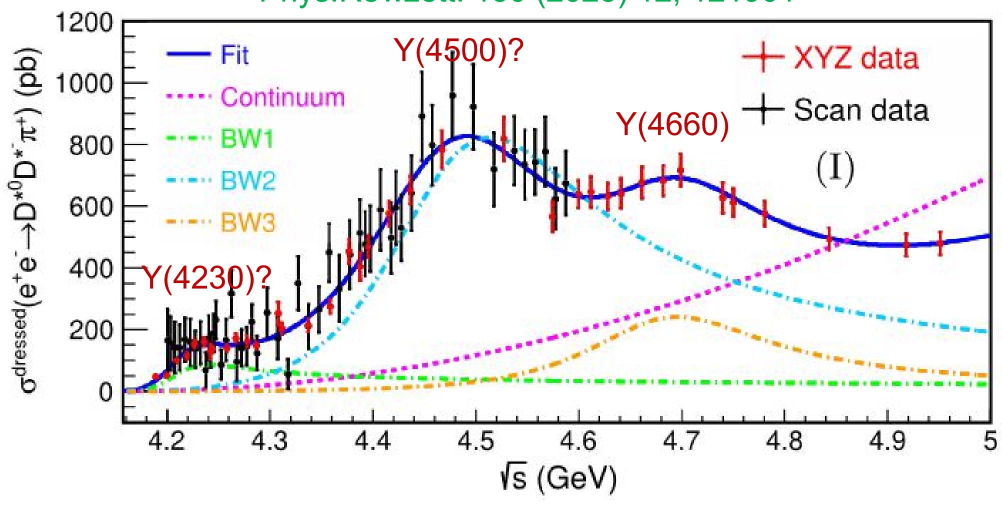
Parameters	Solution I	Solution II
$M[R_1]$	$4406.9 \pm 17.2 \pm 4.5$	
$\Gamma_{tot}[R_1]$	$128.1 \pm 37.2 \pm 2.3$	
$\Gamma_{e^+e^-}\mathcal{B}_1^{R_1}\mathcal{B}_2$	$0.36 \pm 0.10 \pm 0.03$	$0.30 \pm 0.09 \pm 0.03$
$M[R_2]$	$4647.9 \pm 8.6 \pm 0.8$	
$\Gamma_{tot}[R_2]$	$33.1 \pm 18.6 \pm 4.1$	
$\Gamma_{e^+e^-}\mathcal{B}_1^{R_2}\mathcal{B}_2$	$0.24 \pm 0.07 \pm 0.02$	$0.06 \pm 0.03 \pm 0.01$
ϕ	$267.1 \pm 16.2 \pm 3.2$	$-324.8 \pm 43.0 \pm 5.7$



Cross section of $e^+e^- \to D^{*0}D^{*-}\pi^+$

Resonance	Mass (MeV/c²)	Width (MeV/c²)
Y(4210)	$4209.6 \pm 4.7 \pm 5.9$	$81.6 \pm 17.8 \pm 9.0$
Y(4470)	$4469.1 \pm 26.2 \pm 3.6$	$246.3 \pm 36.7 \pm 9.4$
Y(4660)	$4675.3 \pm 29.5 \pm 3.5$	$218.3 \pm 72.9 \pm 9.3$

Phys.Rev.Lett. 130 (2023) 12, 121901



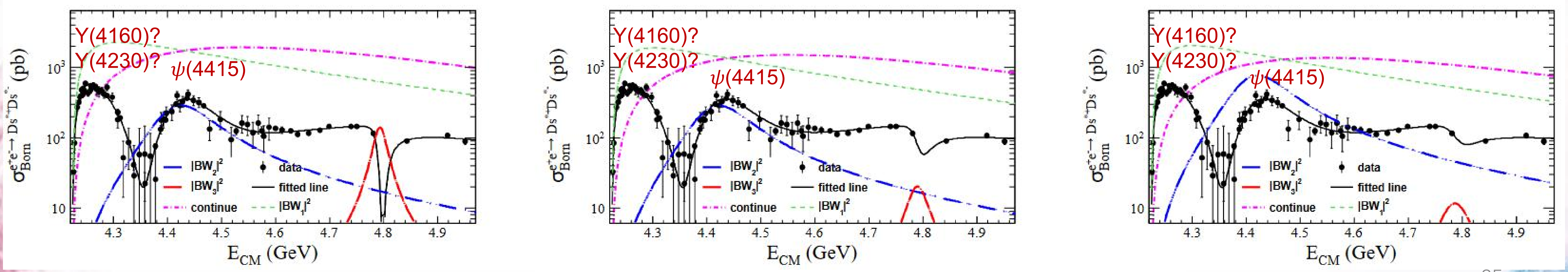
- R_1: if assuming the Y(4230) [Adv.High Energy Phys. 2018 (2018) 5428734]
  - $\Gamma(D^0D^{*-}\pi^+) \sim \Gamma(D^{*0}D^{*-}\pi^+)$
  - $\Gamma(e^+e^-)$>40 eV, disfavoring the hybrid interpretation [Chin.Phys.C 40 (2016) 8, 081002]
- R_2: consistent with Y(4500) observed in $e^+e^- \to K^+K^-J/\psi$ [Chin.Phys.C 46 (2022) 11, 111002]
  - $\Gamma(D^{*0}D^{*-}\pi^+)$ becomes two orders of magnitude of $\Gamma(K^+K^-J/\psi)$
  - contradicts with hidden-strangeness tetraquark conjecture [Phys.Rev.D 73 (2006) 094510, Progr.Phys. 41 (2021) 65-93, Phys.Rev.D 107 (2023) 1, 016001]
- R_3: consistent with Y(4660) [Phys.Rev.D 104 (2021) 5, 052012]
  - first observation of open charm decay mode

Cross section of $e^+e^- \to D^{*+}D^{*-}$

- R_1:
  - ✓ consistent with Y(4160) [Phys.Lett.B 660 (2008) 315-319, Phys.Rev.Lett. 111 (2013) 11, 112003,]
  - ✓ consistent also with Y(4230) considering the systematic uncertainty [Phys.Rev.D 106 (2022) 7, 072001], which will indicate Y(4230) couples more strongly to open charm final states than to charmonia
- R_2:
  - ✓ consistent with $\psi(4415)$
  - ✓ the first time to observe $\psi(4415)$ in $D^{*+}D^{*-}$ final state

Resonance	Mass (MeV/c²)	Width (MeV/c²)
Y(4160)/Y(4230)	$4186.5 \pm 9.0 \pm 30$	$55 \pm 17 \pm 53$
$\psi(4415)$	$4469.1 \pm 26.2 \pm 3.6$	$246.3 \pm 36.7 \pm 9.4$

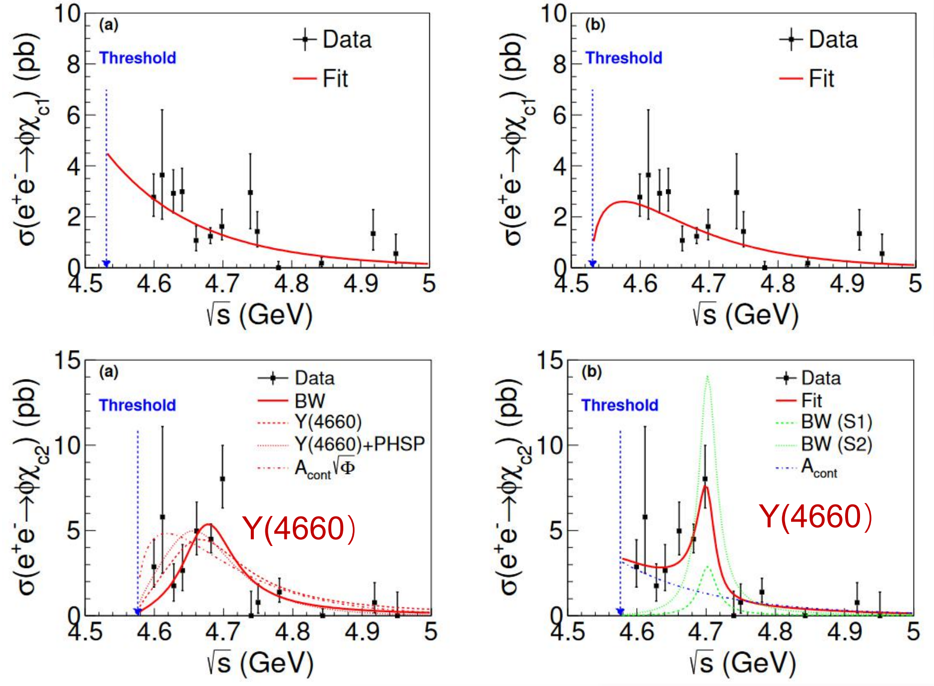
arxiv: 2305.10789



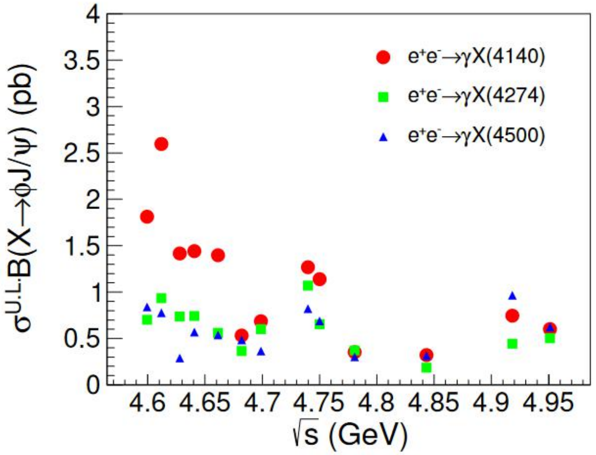
Cross section of $e^+e^- \to \gamma\phi J/\psi$

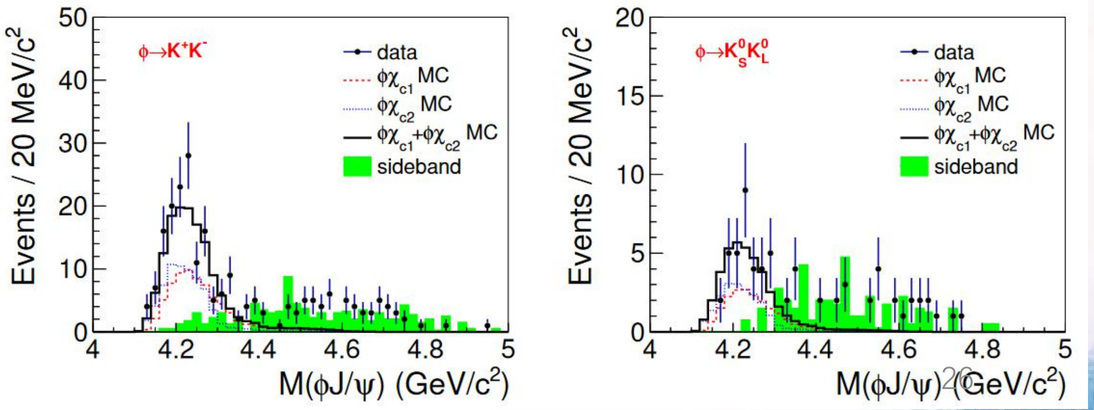
JHEP 01 (2023) 132

- For the case of $\phi\chi_{c1}$
  - ✓ No obvious resonance observed
- For the case of $\phi\chi_{c2}$
  - ✓ Evidence for Y(4660) is observed with 3.1σ fitted by a single BW ($M = 4672.8 \pm 10.8 \pm 3.9\ \mathrm{MeV}/c^2$, $\Gamma = 93.2 \pm 19.8 \pm 9.4\ \mathrm{MeV}$)
  - ✓ 3.6σ fitted by the coherent sum of a BW and continuum ($M = 4701.8 \pm 10.9 \pm 2.7\ \mathrm{MeV}/c^2$, $\Gamma = 30.5 \pm 22.3 \pm 14.6\ \mathrm{MeV}$)
  - ✓ The first evident structure observed in $\phi\chi_{c2}$ system



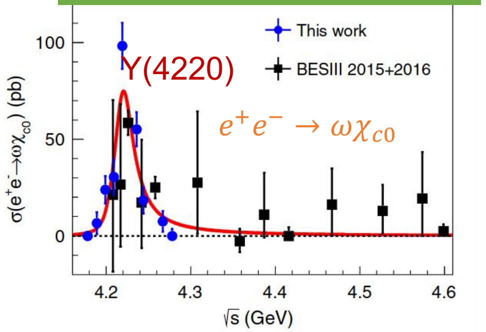
No evident hint for X(4140), X(4274) and X(4500) in $\phi J/\psi$ system



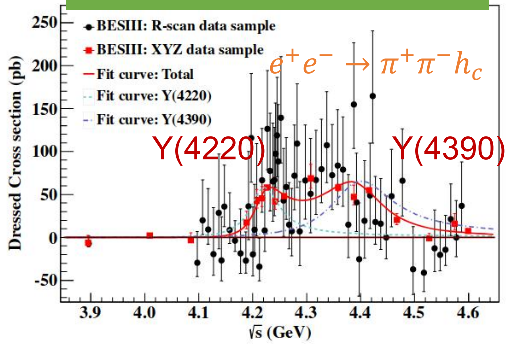


Y states at BESIII

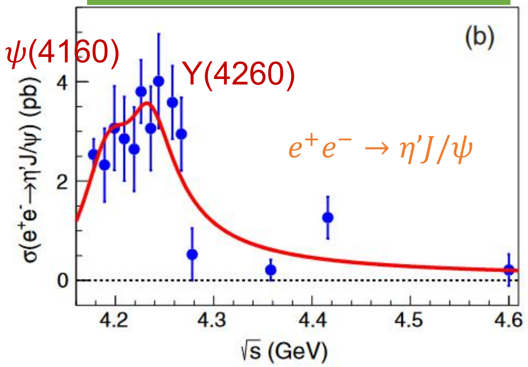
Phys.Rev.D 99 (2019)



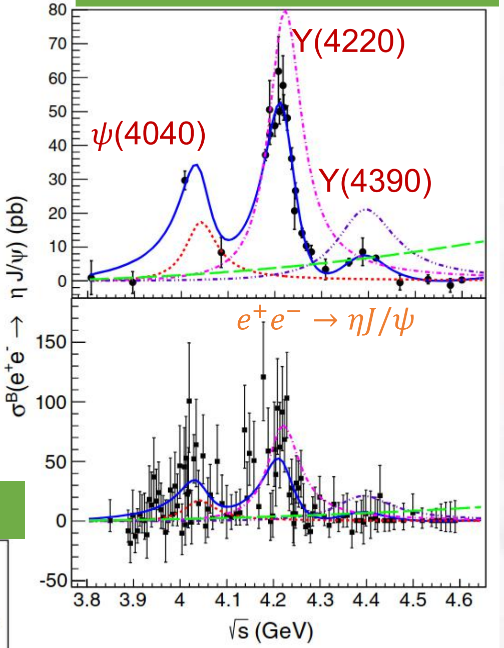
Phys.Rev.Lett. 118 (2017)



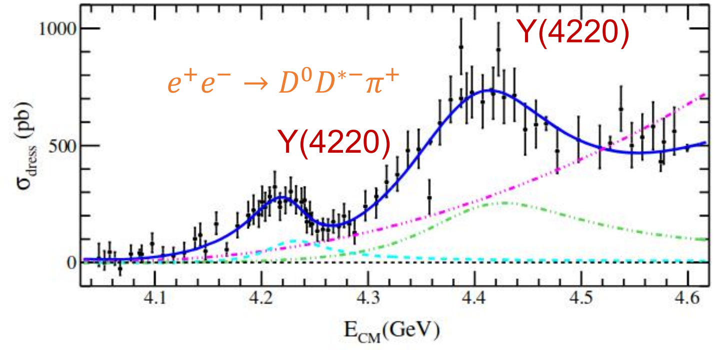
Phys.Rev.D 101 (2020)



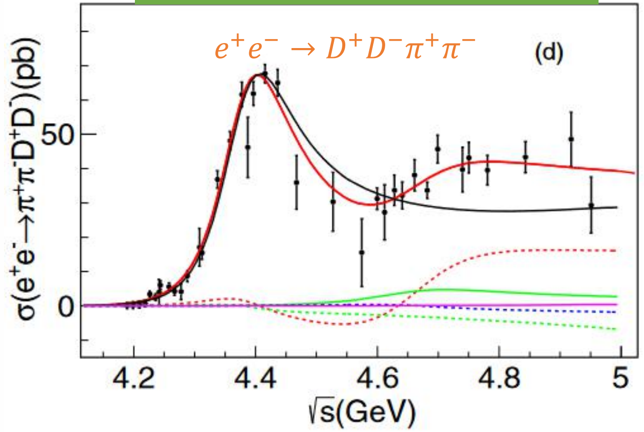
Phys.Rev.D 102 (2020)



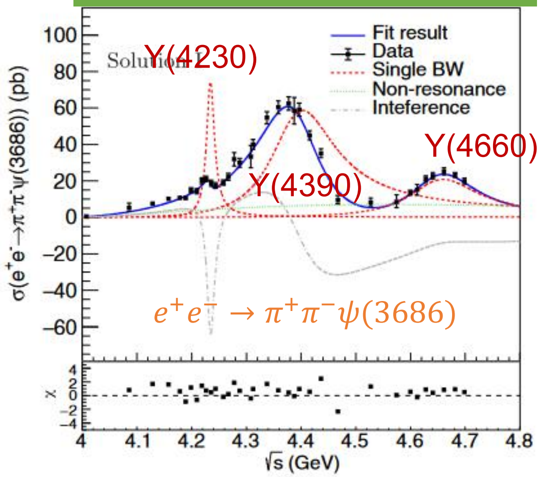
Phys.Rev.Lett. 122 (2019)



Phys.Rev.D 106 (2022)

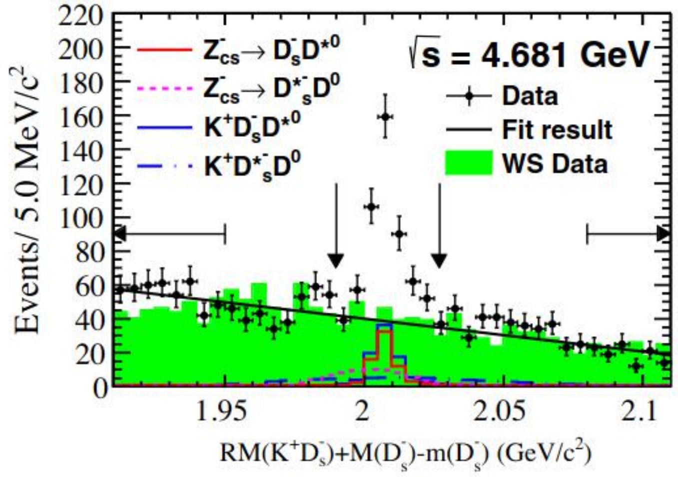


Phys.Rev.D 104 (2021)



$Z_{cs}(3985)^-$ in $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$

Phys. Rev. Lett. 126, 102001 (2021)

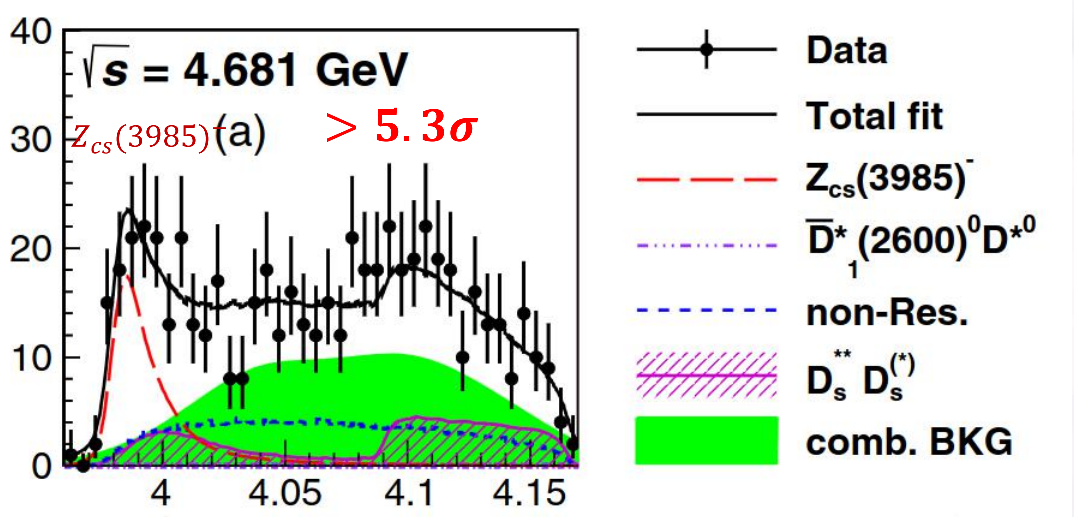


- An enhancement near the $D_s^- D^{*0}$ and $D_s^{*-} D^0$ mass thresholds in the K^+ recoil-mass spectrum
- match the hypothesis of $Z_{cs}(3985)^-$

$$m_{\text{pole}}[Z_{cs}(3985)^-] = (3982.5^{+1.8}_{-2.6} \pm 2.1)\ \text{MeV}/c^2$$

$$\Gamma_{\text{pole}} = [Z_{cs}(3985)^-] = (12.8^{+5.3}_{-4.4} \pm 3.0)\ \text{MeV}$$

- Mostly likely $c\bar{c}s\bar{u}$
- The first Z_{cs} tetraquark candidate observed
- Consistent with the prediction:
  - ✓ relativistic diquark-antidiquark picture [Eur. Phys. J. C (2008) 58: 399–405]
  - ✓ $D_s\bar{D}^* - D_s^*\bar{D}$ molecule [J. Korean Phys. Soc. 55, 424 (2009)]
  - ✓ QCD sum rules [Phys. Rev. D 88, 096014 (2013)]
  - ✓ initial chiral particle emission mechanism [Phys. Rev. Lett. 110, 232001 (2013)]



Evidence of $Z_{cs}(3985)^0$ in $e^+e^- \to K_S^0(D_s^+D^{*-} + D_s^{*+}D^-)$

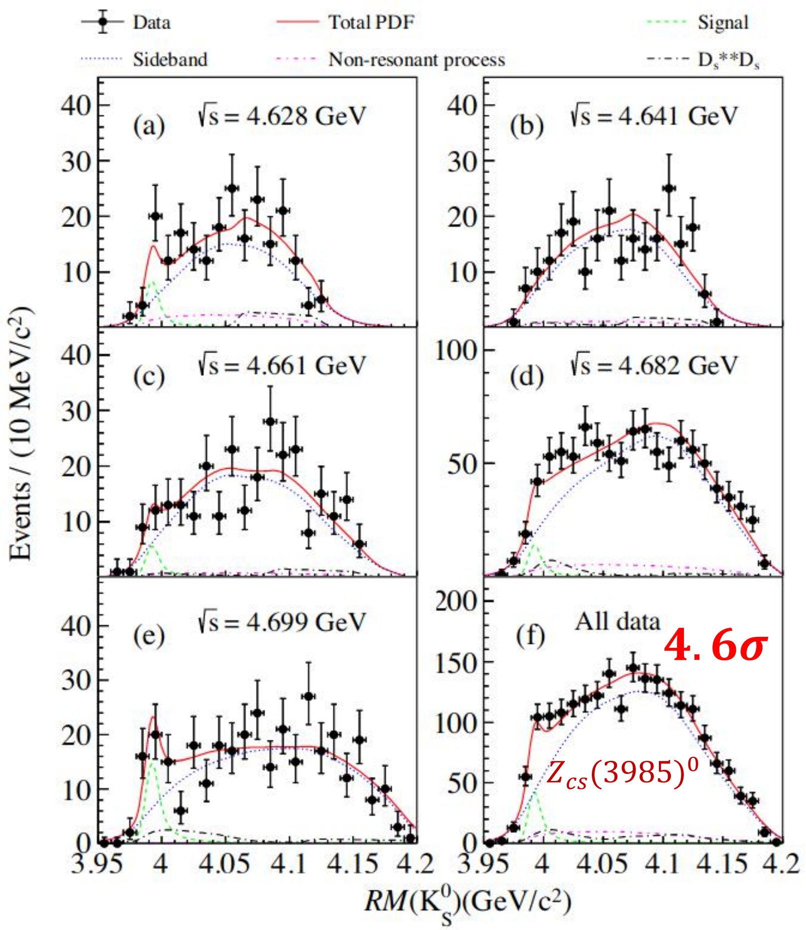
- Evidence of a neutral open-strange hidden-charm state $Z_{cs}(3985)^0$

$$m[Z_{cs}(3985)^0] = (3992.2 \pm 1.7 \pm 1.6)\ \mathrm{MeV}/c^2$$

$$\Gamma = [Z_{cs}(3985)^0] = (7.7^{+4.1}_{-3.8} \pm 4.3)\ \mathrm{MeV}$$

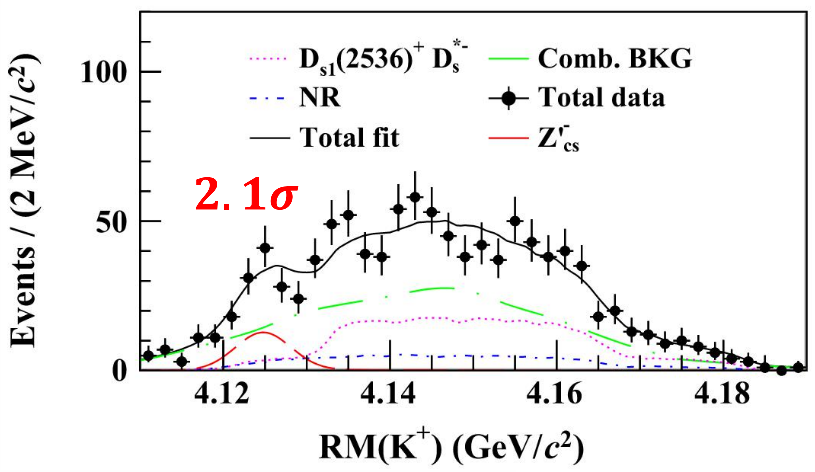
- Mass larger than $Z_{cs}(3985)^-$, consistent with theoretical prediction [Nucl.Phys.B 968 (2021) 115450]
- Mostly likely $c\bar{c}\bar{s}d$
- Born cross sections of $e^+e^- \to \bar{K}^0 Z_{cs}(3985)^0 + c.c.$ is consistent with those of $e^+e^- \to K^- Z_{cs}(3985)^+ + c.c.$ [Phys. Rev. Lett. 126, 102001 (2021)]
- The isospin partner of $Z_{cs}(3985)^+$

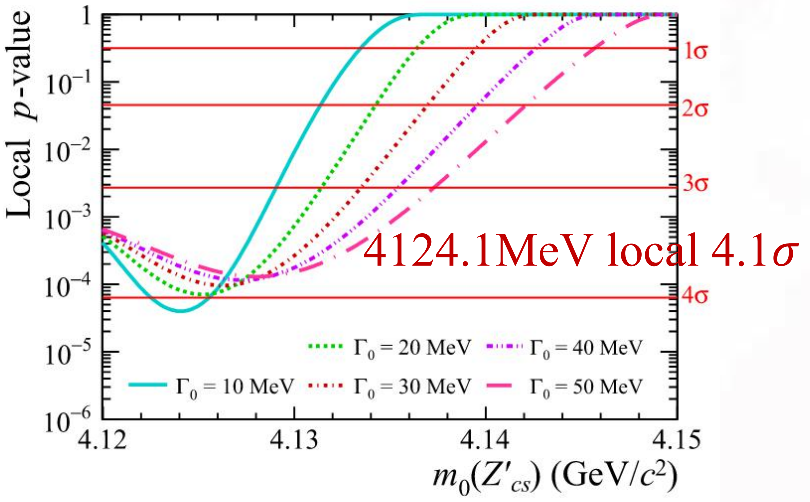
Phys.Rev.Lett. 129 (2022) 11, 112003



Search for charged Z'_{cs} in $e^+e^- \to K^+D_s^{*-}D^{*0} + c.c.$

Chin.Phys.C 47 (2023)

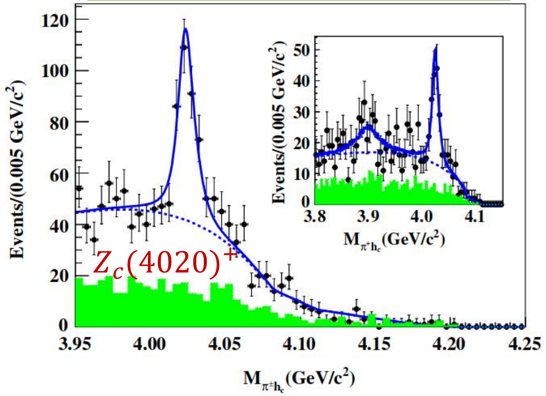




$m[Z'^{-}_{cs}] = (4123.5 \pm 0.7_{\text{stat.}} \pm 4.7_{\text{syst.}})\ \text{MeV}/c^2$

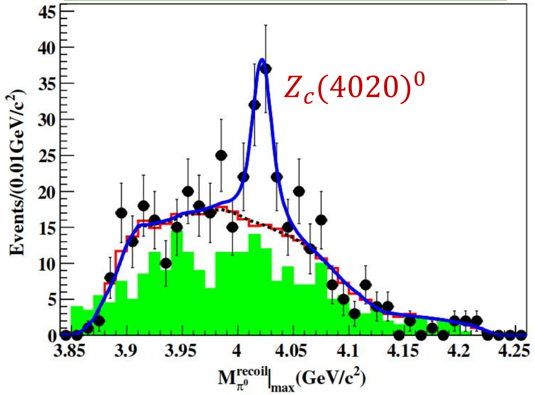
Z_c states at BESIII

PRL 111, 242001 (2013)



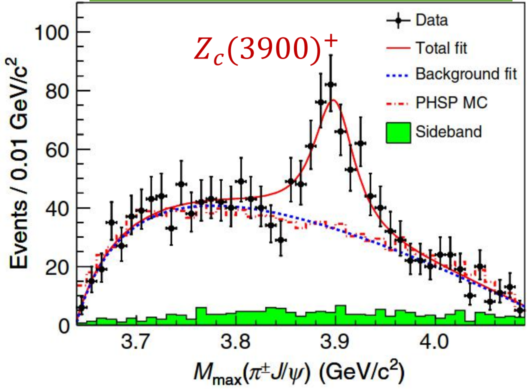
$e^+e^- \to \pi^-\pi^+h_c$

PRL 113, 212002 (2014)



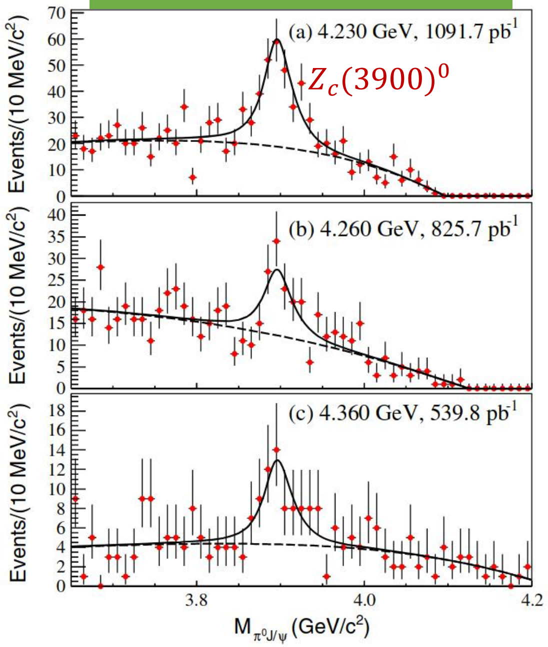
$e^+e^- \to \pi^0\pi^0h_c$

PRL 110, 252001 (2013)



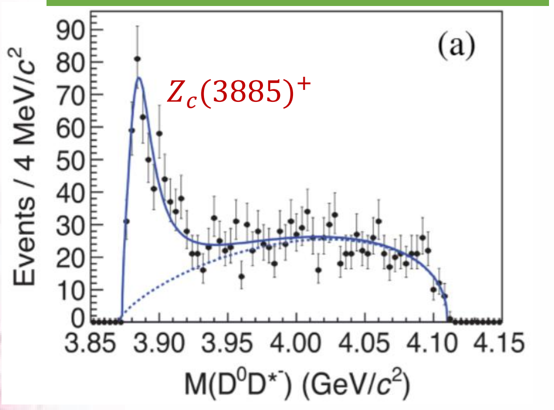
$e^+e^- \to \pi^-\pi^+J/\psi$

PRL 115, 112003 (2015)



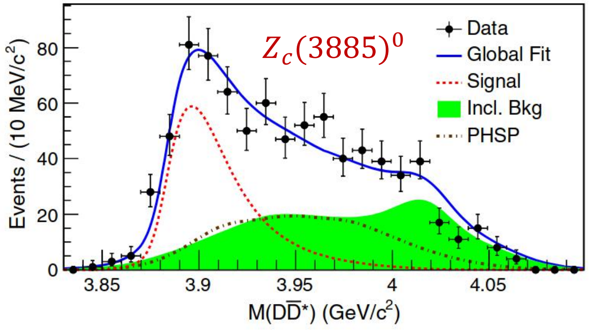
$e^+e^- \to \pi^0\pi^0J/\psi$

ST: PRL 113, 022001 (2014)
DT: PRD 92, 092006 (2015)



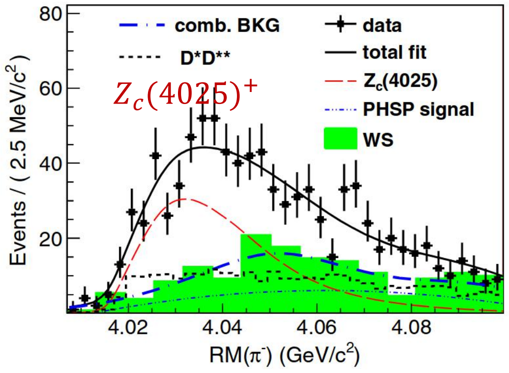
$e^+e^- \to \pi^-(D\bar{D}^*)^+$

PRL 115, 222002 (2015)



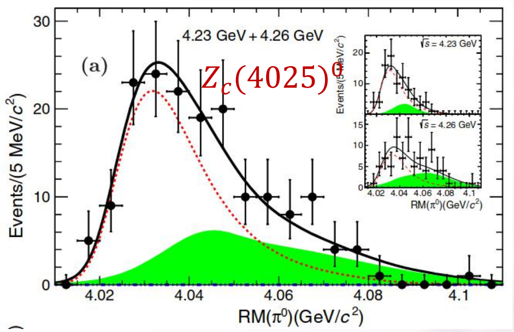
$e^+e^- \to \pi^0(D\bar{D}^*)^0$

PRL 112, 132001 (2014)



$e^+e^- \to \pi^{\mp}(D^*\bar{D}^*)^{\pm}$

PRL 115, 182002 (2015)

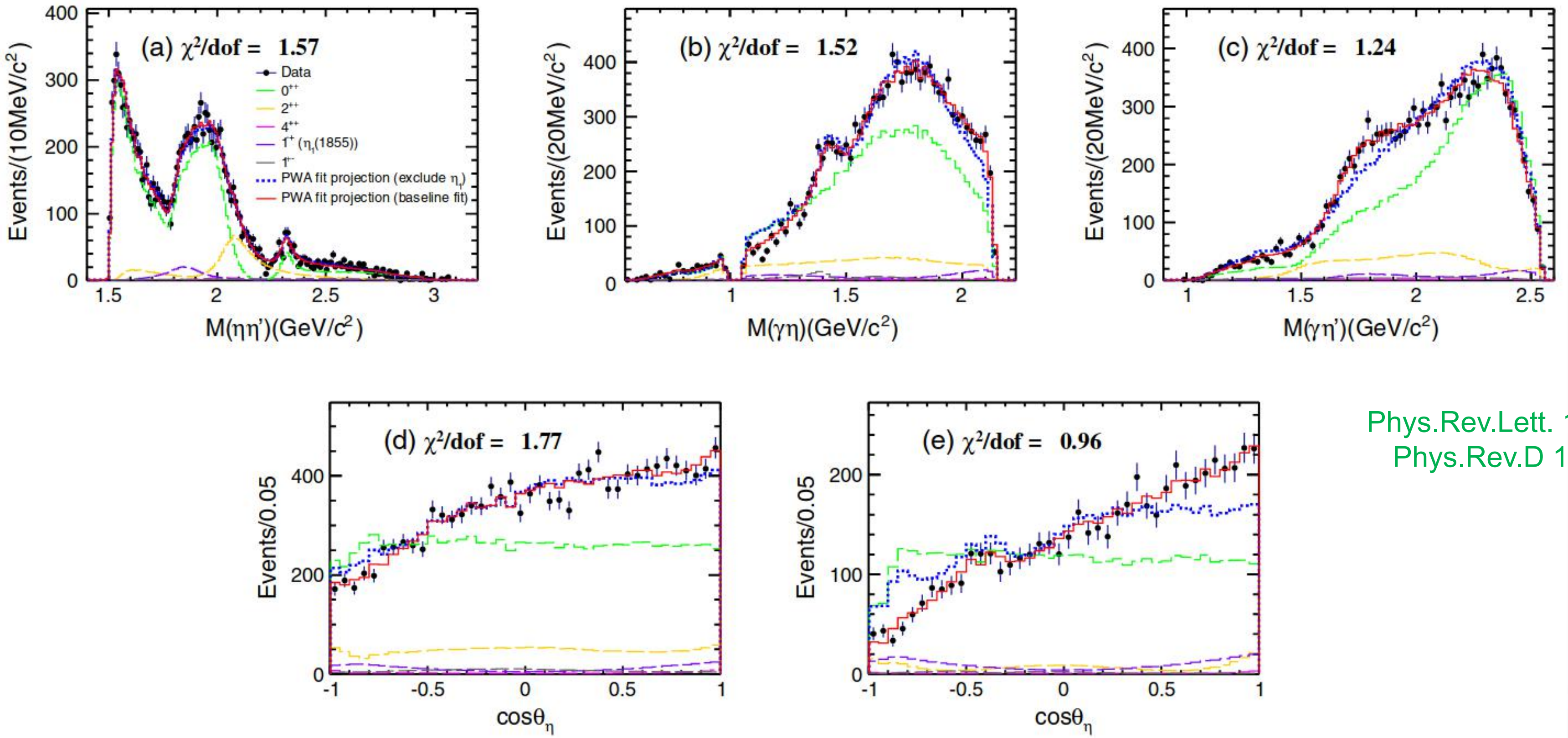


$e^+e^- \to \pi^0(D^*\bar{D}^*)^0$

Content

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

- Quasi two-body decay amplitudes in the sequential decay processes $J/\psi \to \gamma X, X \to \eta\eta'$, $J/\psi \to \eta X, X \to \gamma\eta'$ and $J/\psi \to \eta' X, X \to \gamma\eta$ are constructed using the covariant tentor formalism
- All kinematically allowed known resonances with 0^{++}, 2^{++}, 4^{++} ($\eta\eta'$) and 1^{+-}, 1^{-+} ($\gamma\eta^{(\prime)}$) are considered
- 1^{-+} in $\eta\eta'$ system is also considered (η/η' not identical particle)

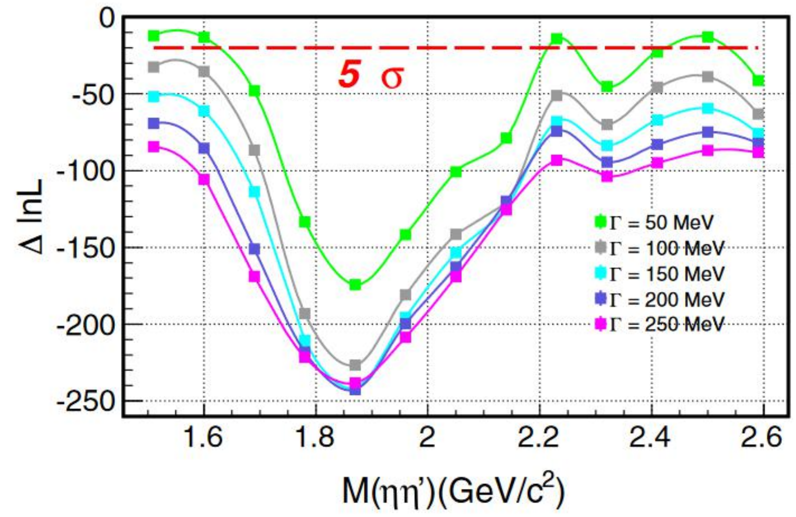


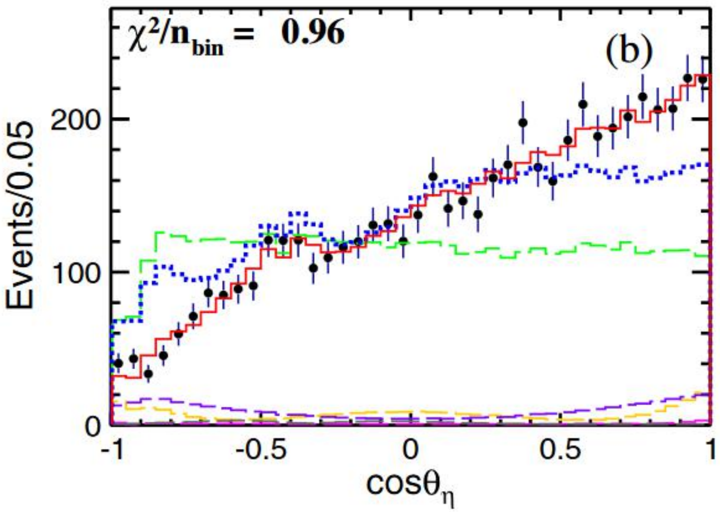
Phys.Rev.Lett. 129 (2022) 19, 192002
Phys.Rev.D 106 (2022) 7, 072012

Observation of exotic isoscalar meson $\eta_1(1855)$

Resonance	M (MeV/c^2)	Γ (MeV)	B.F.($\times 10^{-5}$)	Sig.
$f_0(1500)$	1506	112	$1.81 \pm 0.11^{+0.19}_{-0.13}$	$> 30\sigma$
$f_0(1810)$	1795	95	$0.11 \pm 0.01^{+0.04}_{-0.03}$	11.1σ
$f_0(2020)$	$2010 \pm 6^{+6}_{-4}$	$203 \pm 9^{+13}_{-11}$	$2.28 \pm 0.12^{+0.29}_{-0.20}$	24.6σ
$f_0(2330)$	$2312 \pm 7^{+7}_{-3}$	$65 \pm 10^{+3}_{-12}$	$0.10 \pm 0.02^{+0.01}_{-0.02}$	13.2σ
$\eta_1(1855)$	$1855 \pm 9^{+6}_{-1}$	$188 \pm 18^{+3}_{-8}$	$0.27 \pm 0.04^{+0.02}_{-0.04}$	21.4σ
$f_2(1565)$	1542	122	$0.32 \pm 0.05^{+0.12}_{-0.02}$	8.7σ
$f_2(2010)$	$2062 \pm 6^{+10}_{-7}$	$165 \pm 17^{+10}_{-5}$	$0.71 \pm 0.06^{+0.10}_{-0.06}$	13.4σ
$f_4(2050)$	2018	237	$0.06 \pm 0.01^{+0.03}_{-0.01}$	4.6σ
0^{++} PHSP	...	...	$1.44 \pm 0.15^{+0.10}_{-0.20}$	15.7σ
$h_1(1415)$	1416	90	$0.08 \pm 0.01^{+0.01}_{-0.02}$	10.2σ
$h_1(1595)$	1584	384	$0.16 \pm 0.02^{+0.03}_{-0.01}$	9.9σ

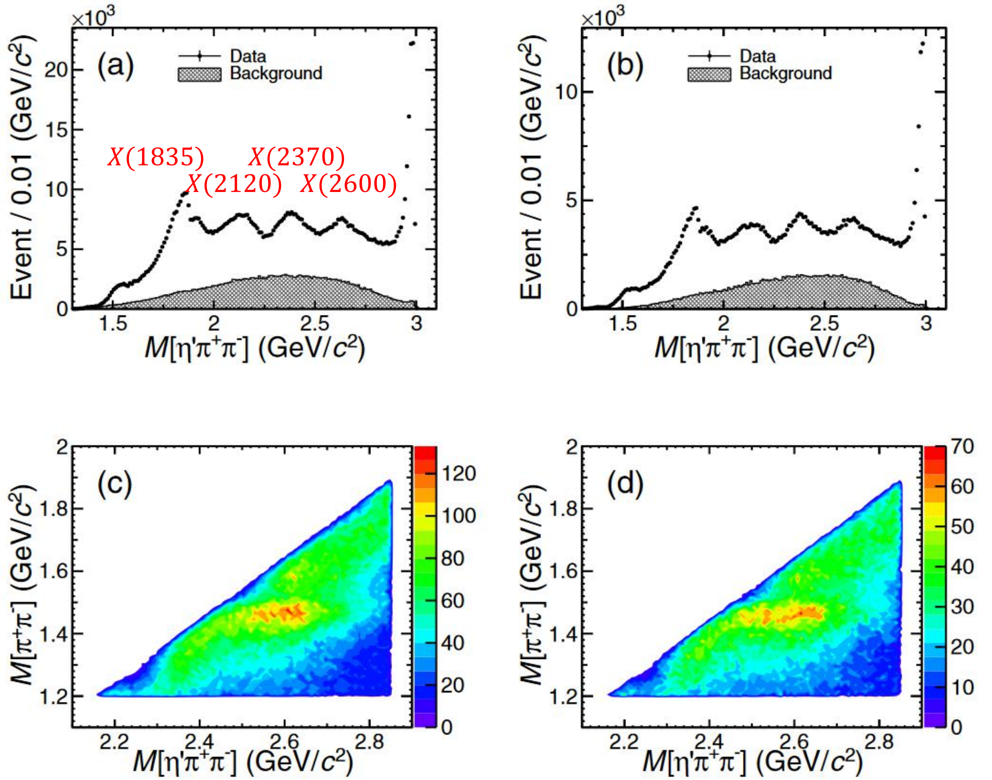
- Assuming $\eta_1(1855)$ is an additional resonance, scans of with different masses and widths
- $M_{\eta_1(1855)} = 1855 \pm 9^{+6}_{-1}\ \mathrm{MeV}/c^2$
- $\Gamma_{\eta_1(1855)} = 188 \pm 18^{+3}_{-8}\ \mathrm{MeV}$
- Some poential models:
  - ✓ hybrid meson [Chin.Phys.C 46 (2022) 5, 051001, Chin.Phys.Lett. 39 (2022) 5, 051201]
  - ✓ tetraquark [Phys.Rev.D 106 (2022) 7, 074003]
  - ✓ Molecule [Nucl.Phys.A 1030 (2023) 122571]





Phys.Rev.Lett. 129 (2022) 19, 192002
Phys.Rev.D 106 (2022) 7, 072012

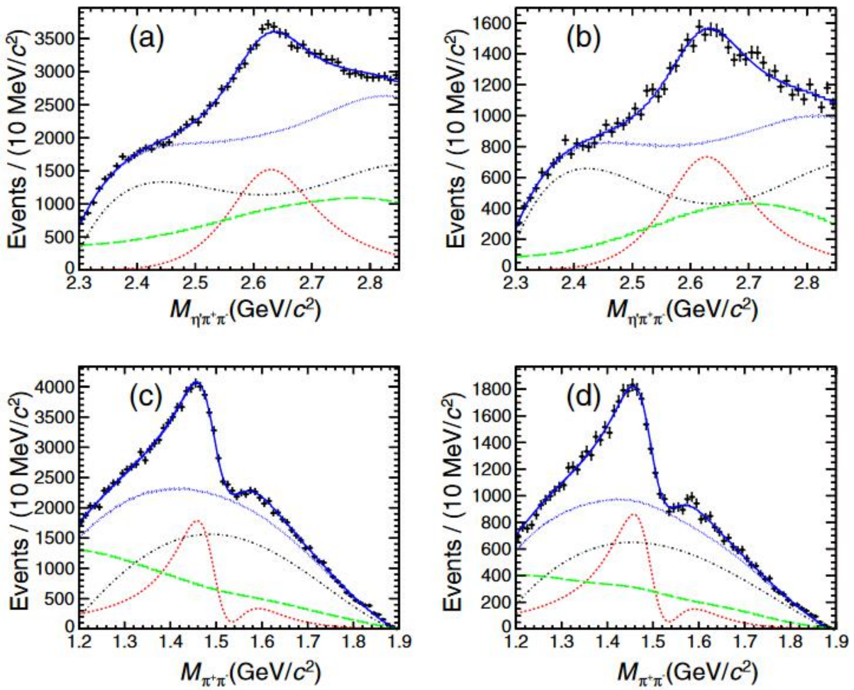
$X(2600)$ in $J/\psi \to \gamma\pi^+\pi^-\eta'$



Resonance	Mass (MeV/c^2)	Width (MeV)
$f_0(1500)$	$1492.5 \pm 3.6^{+2.4}_{-20.5}$	$107 \pm 9^{+21}_{-7}$
$X(1540)$	$1540.2 \pm 7.0^{+36.3}_{-6.1}$	$157 \pm 19^{+11}_{-77}$
$X(2600)$	$2618.3 \pm 2.0^{+16.3}_{-1.4}$	$195 \pm 5^{+26}_{-17}$

Phys.Rev.Lett. 129 (2022) 4, 042001

- 10B J/ψ events are analyzed, where $X(2120)$ and $X(2370)$ are confirmed
- A new state $\mathbf{X(2600)}$ in $\pi^+\pi^-\eta'$ final states is observed with significance >20σ, which is correlated to a structure @1.5 GeV/c^2 in $M(\pi^+\pi^-)$
- Simultaneous fit to $M(\pi^+\pi^-\eta')$ and $M(\pi^+\pi^-)$: interference of $f_0(1500)$ and X$(15??)$ in $\pi^+\pi^-$
- $X(2600)$: 0^{-+} or 2^{-+} is favored. η radial excitation, or exotics?
- $X(1540)$: $f_2'(1525)$ or $f_2(1565)$?



EM Dalitz Decay of $J/\psi \to e^+e^-\pi^+\pi^-\eta'$

Phys.Rev.Lett. 129 (2022) 2, 022002

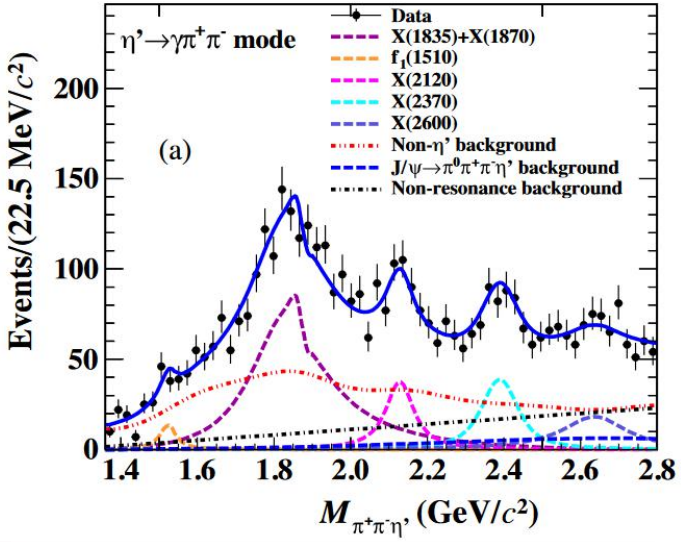
Branching fractions of $J/\psi \to e^+e^-X$, $X \to \pi^+\pi^-\eta'$	
$X = X(1835)$ (solution I)	$(3.58 \pm 0.19 \pm 0.16) \times 10^{-6}$
(solution II)	$(4.43 \pm 0.23 \pm 0.19) \times 10^{-6}$
$X = X(2120)$	$(0.82 \pm 0.12 \pm 0.06) \times 10^{-6}$
$X = X(2370)$	$(1.08 \pm 0.14 \pm 0.10) \times 10^{-6}$

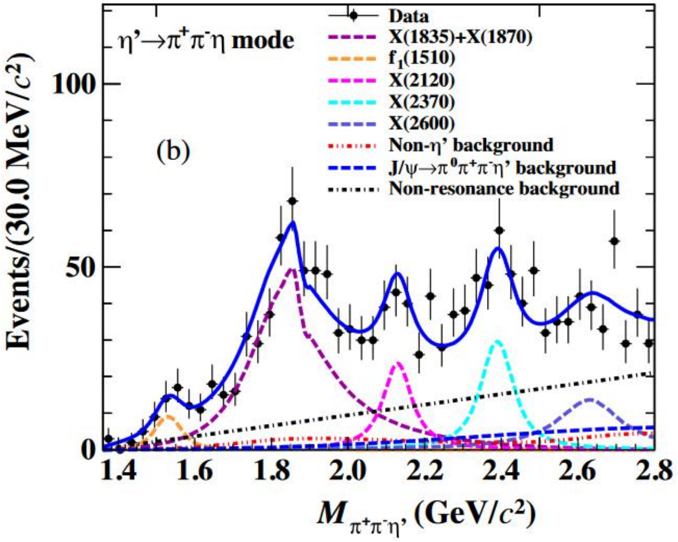
- Observation of $X(1835)$, $X(2120)$, and $X(2370)$ in EM Dalitz decays
- First measurement of the TFF between J/ψ and $X(1835)$

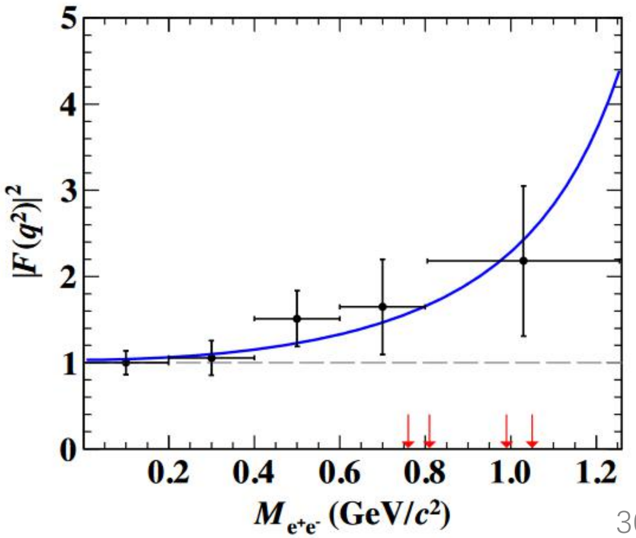
$$F(q^2) = \frac{1}{1 - q^2/\Lambda^2}$$

$$\Lambda = 1.75 \pm 0.29 \pm 0.05\ \mathrm{GeV}/c^2$$

$$\frac{d\Gamma(J/\psi \to X(1835)e^+e^-)}{dq^2\Gamma(J/\psi \to X(1835)\gamma)} = |F(q^2)|^2 \times [\mathrm{QED}(q^2)],$$





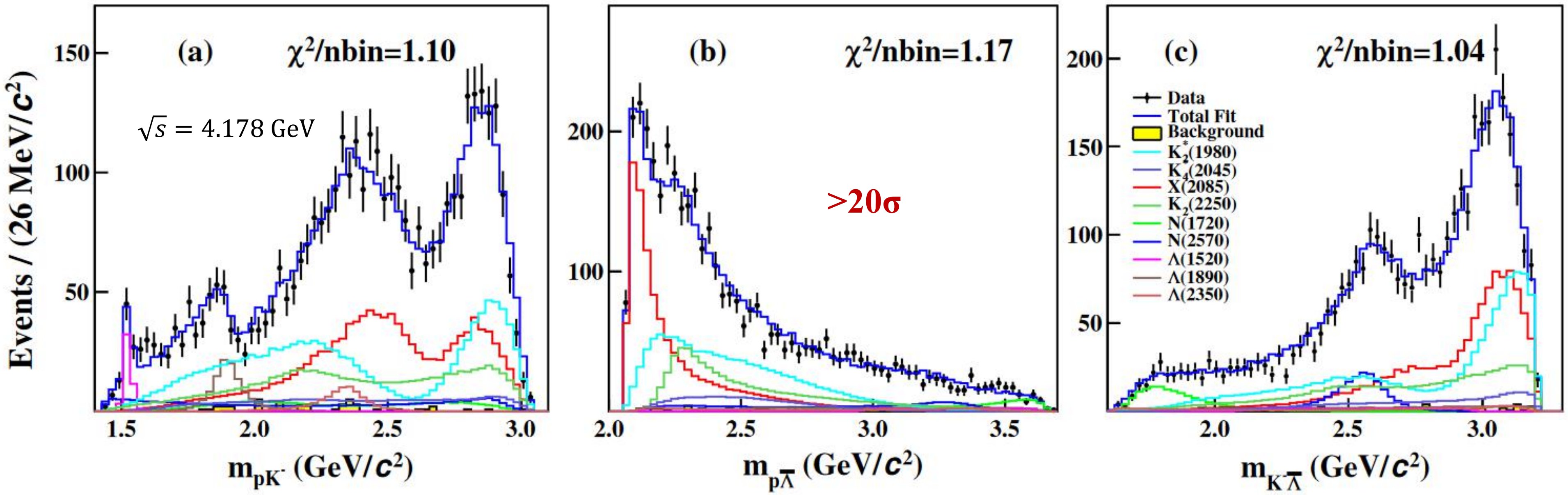


$X(2085)$ in $e^+e^- \to pK\bar{\Lambda}$

arxiv: 2303.01989

- $p\bar{\Lambda}$ resonance parameters and spin-parity:
  - pole mass: (2086±4±6) MeV/c^2
  - pole width: (56±5±16) MeV
  - favor 1^+
- no corresponding excited kaon candidates in experiment or in quark model prediction
- could be an exotic state

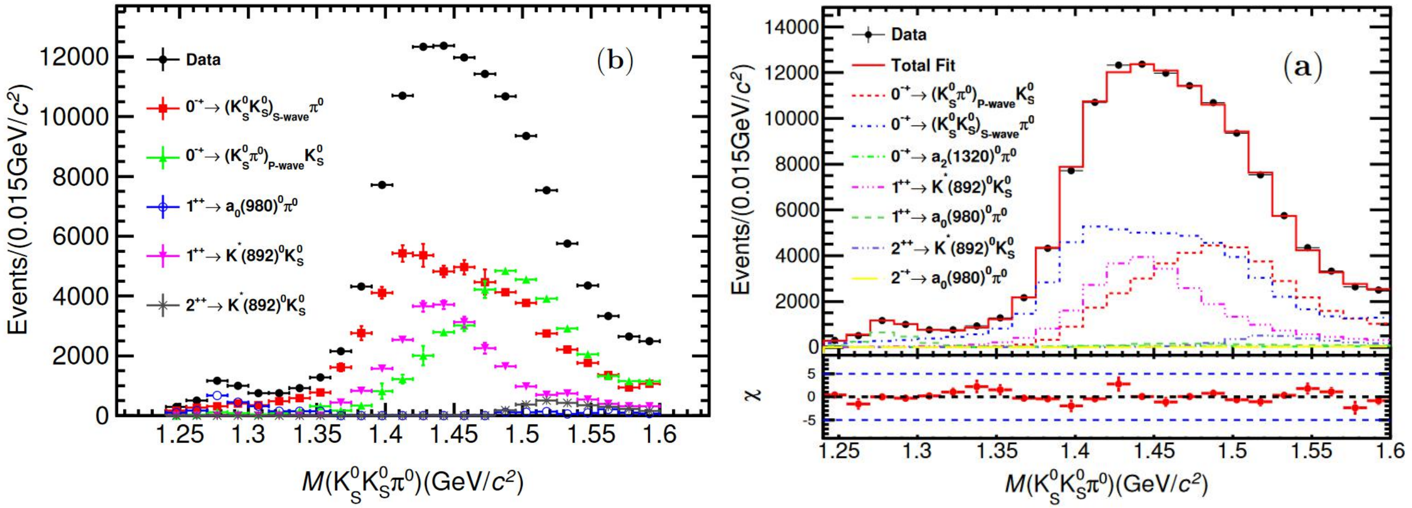
Source	$M_{\rm pole}$ (MeV)	$\Gamma_{\rm pole}$ (MeV)
Radius d	4.8	15.2
Excited Σ states	2.7	4.8
Resonance parameters	0.8	1.7
$\lvert\cos\theta_K\rvert$ requirement	0.4	0.2
$\Lambda(\bar{\Lambda})$ signal mass window	0.8	1.2
Background estimation	1.3	2.0
Mass resolution	0.3	0.2
Total	5.8	16.2



$\eta(1405)/\eta(1475)$ in $J/\psi \to \gamma K_S^0 K_S^0 \pi^0$

JHEP 03 (2023) 121

- Result from mass independent and dependent partial wave analysis show good consistent with each other
- pseudoscalar and axial vector components are the dominant contributions
- $f_2(1525) \to K^*(892)^0 K_S^0$ first observed



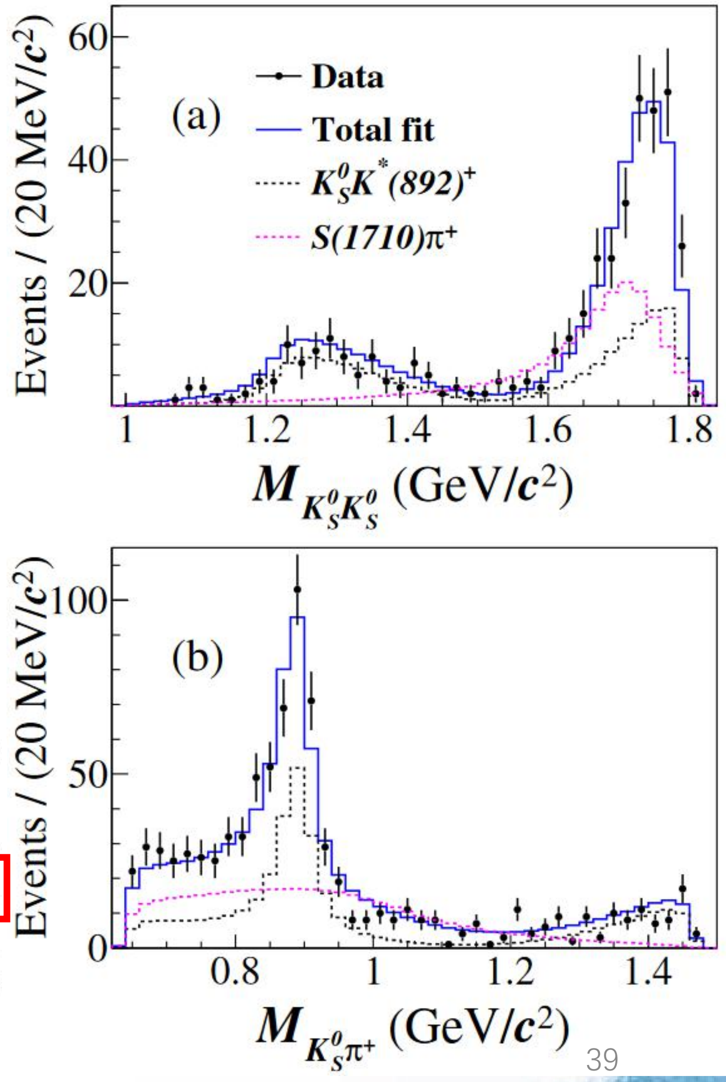
Resonance	M(MeV/c^2)	Γ(MeV)	Decay Mode	B.F.	Sig.(σ)
$\eta(1405)$	$1391.7 \pm 0.7^{+11.3}_{-0.3}$	$60.8 \pm 1.2^{+5.5}_{-12.0}$	$J/\psi \to \gamma\eta(1405) \to \gamma K_S^0(K_S^0\pi^0)_{\text{P-wave}} \to \gamma K_S^0K_S^0\pi^0$	$(5.84 \pm 0.12^{+2.03}_{-3.36}) \times 10^{-5}$	$\gg 35$
			$J/\psi \to \gamma\eta(1405) \to \gamma(K_S^0K_S^0)_{\text{S-wave}}\pi^0 \to \gamma K_S^0K_S^0\pi^0$	$(2.88 \pm 0.04^{+1.64}_{-0.38}) \times 10^{-5}$	18.4
$\eta(1475)$	$1507.6 \pm 1.6^{+15.5}_{-32.2}$	$115.8 \pm 2.4^{+14.8}_{-10.9}$	$J/\psi \to \gamma\eta(1475) \to \gamma K_S^0(K_S^0\pi^0)_{\text{P-wave}} \to \gamma K_S^0K_S^0\pi^0$	$(6.58 \pm 0.12^{+3.98}_{-2.82}) \times 10^{-5}$	$\gg 35$
			$J/\psi \to \gamma\eta(1475) \to \gamma(K_S^0K_S^0)_{\text{S-wave}}\pi^0 \to \gamma K_S^0K_S^0\pi^0$	$(3.99 \pm 0.09^{+0.41}_{-0.66}) \times 10^{-5}$	$\gg 35$
$f_1(1285)$	$1280.2 \pm 0.6^{+1.2}_{-1.5}$	$28.2 \pm 1.1^{+5.5}_{-2.9}$	$J/\psi \to \gamma f_1(1285) \to \gamma a_0(980)^0\pi^0 \to \gamma K_S^0K_S^0\pi^0$	$(8.55 \pm 0.41^{+3.42}_{-1.04}) \times 10^{-6}$	$\gg 35$
$f_1(1420)$	$1433.5 \pm 1.1^{+27.9}_{-0.7}$	$95.9 \pm 2.3^{+13.6}_{-10.9}$	$J/\psi \to \gamma f_1(1420) \to \gamma K^*(892)^0K_S^0 \to \gamma K_S^0K_S^0\pi^0$	$(7.25 \pm 0.12^{+0.73}_{-1.25}) \times 10^{-5}$	$\gg 35$
			$J/\psi \to \gamma f_1(1420) \to \gamma a_0(980)^0\pi^0 \to \gamma K_S^0K_S^0\pi^0$	$(4.62 \pm 0.36^{+2.36}_{-1.94}) \times 10^{-6}$	17.8
$f_2(1525)$	$1515.4 \pm 2.5^{+3.2}_{-7.6}$	$64.0 \pm 4.3^{+2.0}_{-6.1}$	$J/\psi \to \gamma f_2(1525) \to \gamma K^*(892)^0K_S^0 \to \gamma K_S^0K_S^0\pi^0$	$(9.47 \pm 0.43^{+1.51}_{-0.66}) \times 10^{-6}$	23.8

well describe the pseudoscalar components

$f_0(1710)$ in $D_s^+ \to K_S^0 K_S^0 \pi^+$

Phys.Rev.D 105 (2022) 5, L051103

- $Br(D_s^+ \to K_S^0 K_S^0 \pi^+) = (0.68 \pm 0.04_{\text{stat.}} \pm 0.01_{\text{syst.}})\%$, consistent with CLEO result
- $M_{f_0(1710)} = (1.723 \pm 0.011_{\text{stat}} \pm 0.002_{\text{syst}})\ \text{GeV}/c^2$
- $\Gamma_{f_0(1710)} = (0.140 \pm 0.014_{\text{stat}} \pm 0.004_{\text{syst}})\ \text{GeV}/c^2$
- $\frac{Br(f_0(1710) \to K^+K^-)}{Br(f_0(1710) \to K_S^0 K_S^0)} = 0.32 \pm 0.12$ (implies existence of an isospin one partner of the $f_0(1710)$. Constructive interference for charged kaons and destructive interference for neutral kaons)
- More close to the $K^*\bar{K}^*$ molecule hypothesis of $f_0(1710)$ [Phys.Rev.D 79 (2009) 074009, Phys.Rev.D 104 (2021) 11, 114001]



2.9σ deviate from CLEO result (interference?) →

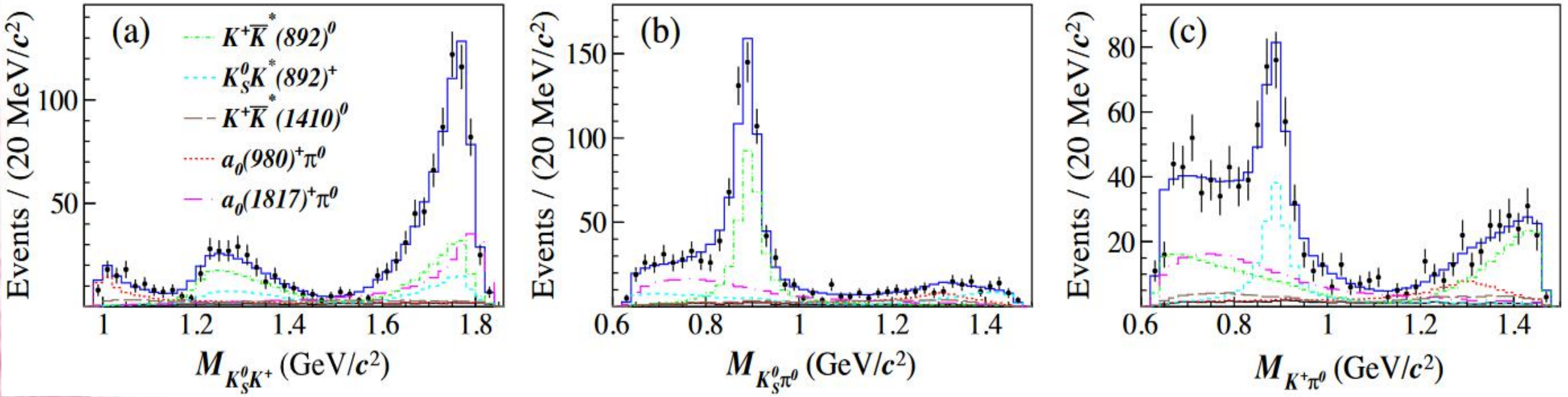
Amplitude	BF (10^{-3})
$D_s^+ \to K_S^0 K^*(892)^+ \to K_S^0 K_S^0 \pi^+$	$3.0 \pm 0.3 \pm 0.1$
$D_s^+ \to S(1710)\pi^+ \to K_S^0 K_S^0 \pi^+$	$3.1 \pm 0.3 \pm 0.1$

$a_0(1817)^+$ in $D_s^+ \to K_S^0 K^+ \pi^0$

Phys.Rev.Lett. 129 (2022) 18, 18

- $Br(D_s^+ \to K_S^0 K^+ \pi^0) = (1.46 \pm 0.06_{\text{stat.}} \pm 0.06_{\text{syst.}})\%$, consistent with CLEO result
- $a_0(1817)^+$ first observed with significance larger than 10σ
- $M_{a_0(1817)^+} = (1.817 \pm 0.008_{\text{stat}} \pm 0.020_{\text{syst}})\ \text{GeV}/c^2$
- $\Gamma_{a_0(1817)^+} = (0.097 \pm 0.022_{\text{stat}} \pm 0.015_{\text{syst}})\ \text{GeV}/c^2$
- Models:
- isospin-one partner of $f_0(1817)$: BF consistent roughly with prediction [Eur.Phys.J.C 82 (2022) 3, 225] but mass is larger about 100 MeV/c^2
- isospin-one partner of $X(1812)$ [Phys.Rev.D 105 (2022) 11, 114014]

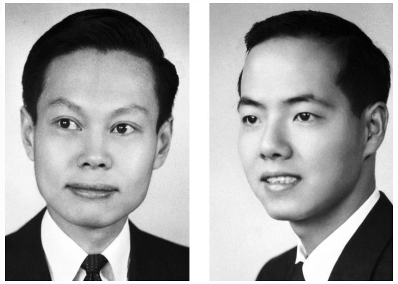
Amplitude	Phase (rad)	FF (%)	BF (10^{-3})	σ
$D_s^+ \to \bar{K}^*(892)^0 K^+$	0.0 (fixed)	$32.7 \pm 2.2 \pm 1.9$	$4.77 \pm 0.38 \pm 0.32$	> 10
$D_s^+ \to K^*(892)^+ K_S^0$	$-0.16 \pm 0.12 \pm 0.11$	$13.9 \pm 1.7 \pm 1.3$	$2.03 \pm 0.26 \pm 0.20$	> 10
$D_s^+ \to a_0(980)^+ \pi^0$	$-0.97 \pm 0.27 \pm 0.25$	$7.7 \pm 1.7 \pm 1.8$	$1.12 \pm 0.25 \pm 0.27$	6.7
$D_s^+ \to \bar{K}^*(1410)^0 K^+$	$0.17 \pm 0.15 \pm 0.08$	$6.0 \pm 1.4 \pm 1.3$	$0.88 \pm 0.21 \pm 0.19$	7.6
$D_s^+ \to a_0(1817)^+ \pi^0$	$-2.55 \pm 0.21 \pm 0.07$	$23.6 \pm 3.4 \pm 2.0$	$3.44 \pm 0.52 \pm 0.32$	> 10



- $\frac{Br(D_s^+ \to \bar{K}^*(892)^0 K^+)}{Br(D_s^+ \to \bar{K}^0 K^*(892)^+)} = 2.35^{+0.42}_{-0.23}\,\text{stat} \pm 0.10_{\text{syst}}$
- $\frac{Br(a_0(980)^+ \to \bar{K}^0 K^+)}{Br(a_0(980)^+ \to \pi^+ \eta)} = 13.7 \pm 3.6_{\text{stat}} \pm 4.2_{\text{syst}}$

Content

CPV in hyperon decay



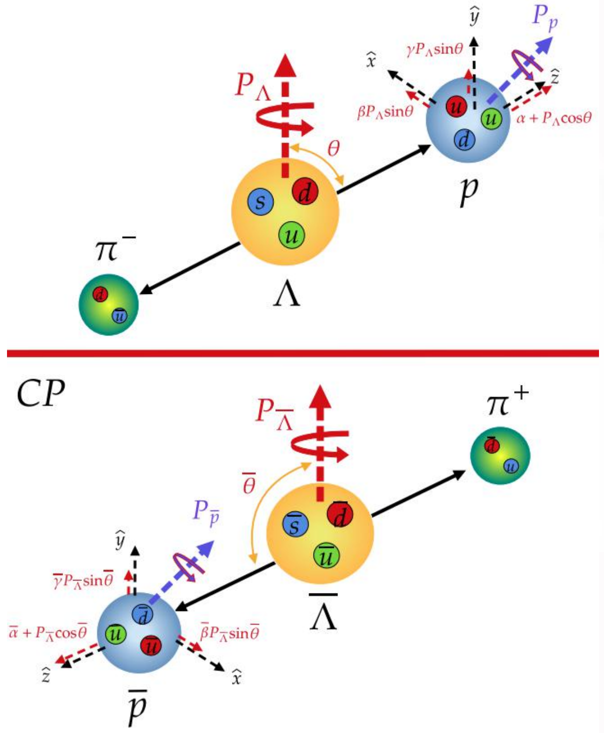
General Partial Wave Analysis of the Decay of a Hyperon of Spin ½

T. D. Lee* and C. N. Yang

Institute for Advanced Study, Princeton, New Jersey

(Received October 22, 1957)

Phys. Rev. 108, 1645 (1957)



The amplitude of spin ½ baryon B_i decay to a spin ½ baryon B_f and π:

$$\mathcal{A} \sim S\sigma_0 + P\boldsymbol{\sigma}\cdot\hat{\boldsymbol{n}}$$

The decay parameters are defined as:

$$\alpha_Y = \frac{2\,\mathrm{Re}\,(S^*P)}{|S|^2+|P|^2},\quad \beta_Y = \frac{2\,\mathrm{Im}\,(S^*P)}{|S|^2+|P|^2},\quad \gamma_Y = \frac{|S|^2-|P|^2}{|S|^2+|P|^2}$$

Two complex amplitudes:

$$S = \Sigma^i S_i e^{i(\phi_i^S+\delta_i^S)},\ \ P = \Sigma^i P_i e^{i(\phi_i^P+\delta_i^P)}$$

Under CP transformation:

$$\bar S = -\Sigma^i S_i e^{i(-\phi_i^S+\delta_i^S)},\ \ \bar P = \Sigma^i P_i e^{i(-\phi_i^P+\delta_i^P)}$$

If CP conserved: $S \xRightarrow{CP} -S$ $\qquad \alpha \xRightarrow{CP} \bar\alpha = -\alpha$

$P \xRightarrow{CP} P$ $\qquad \beta \xRightarrow{CP} \bar\beta = -\beta$

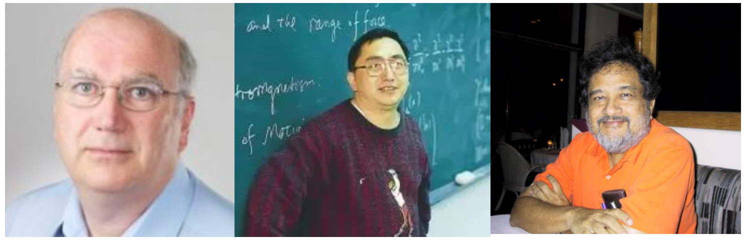
CPV observables:

$$\Delta = \frac{\Gamma-\bar\Gamma}{\Gamma+\bar\Gamma}$$

$$A = \frac{\Gamma\alpha+\bar\Gamma\bar\alpha}{\Gamma\alpha-\bar\Gamma\bar\alpha} \approx \frac{\alpha+\bar\alpha}{\alpha-\bar\alpha}+\Delta$$

$$B = \frac{\Gamma\beta+\bar\Gamma\bar\beta}{\Gamma\beta-\bar\Gamma\bar\beta} \approx \frac{\beta+\bar\beta}{\beta-\bar\beta}+\Delta$$

CP observable in hyperon decay



John F. Donoghue | Xiao-Gang He | Sandip Pakvasa

PHYSICAL REVIEW D VOLUME 34, NUMBER 3 1 AUGUST 1986

Hyperon decays and *CP* nonconservation

John F. Donoghue
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(Received 7 March 1986)

We study all modes of hyperon nonleptonic decay and consider the *CP*-odd observables which result. Explicit calculations are provided in the Kobayashi-Maskawa, Weinberg-Higgs, and left-right-symmetric models of *CP* nonconservation.

PRD 34,833 1986

SM Prediction of Λ decay

Not sensitive to *CPV* → **Decay width difference** $\Delta = \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}} \approx \sqrt{2}\frac{T_{\frac{3}{2}}}{T_{\frac{1}{2}}} \sin \Delta_s \sin \phi_{CP}$ — -5.4×10^{-7}

Easiest to measure → **Decay parameter difference** $A = \frac{\Gamma\alpha + \bar{\Gamma}\bar{\alpha}}{\Gamma\alpha - \bar{\Gamma}\bar{\alpha}} \approx \tan \Delta_s \tan \phi_{CP}$ — -0.5×10^{-4}

Polarization of decayed baryon needs to be measured → **Decay parameter difference** $B = \frac{\Gamma\beta + \bar{\Gamma}\bar{\beta}}{\Gamma\beta - \bar{\Gamma}\bar{\beta}} \approx \tan \phi_{CP}$ — 3.0×10^{-3}

Ξ^-, Ξ^0, Ω^- cascade decay

BESIII: a hyperon factory

10 billion J/ψ events collected:

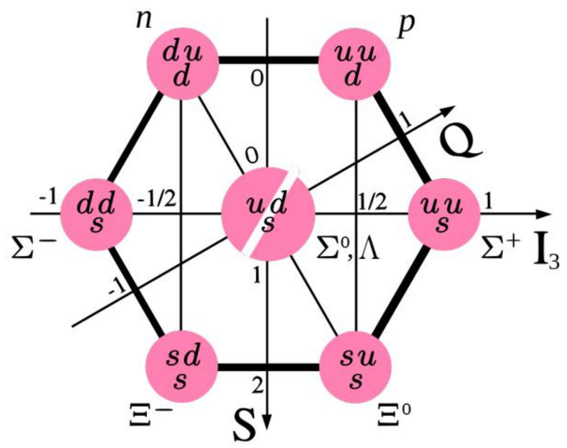
- **Large Br. in J/ψ decay**
- **Quantum entangled pair productions**
- **High efficiency, background free**

Front. Phys. 12(5), 121301 (2017)
Phys. Rev. D 100, 114005 (2019)

CPV in SM is small:

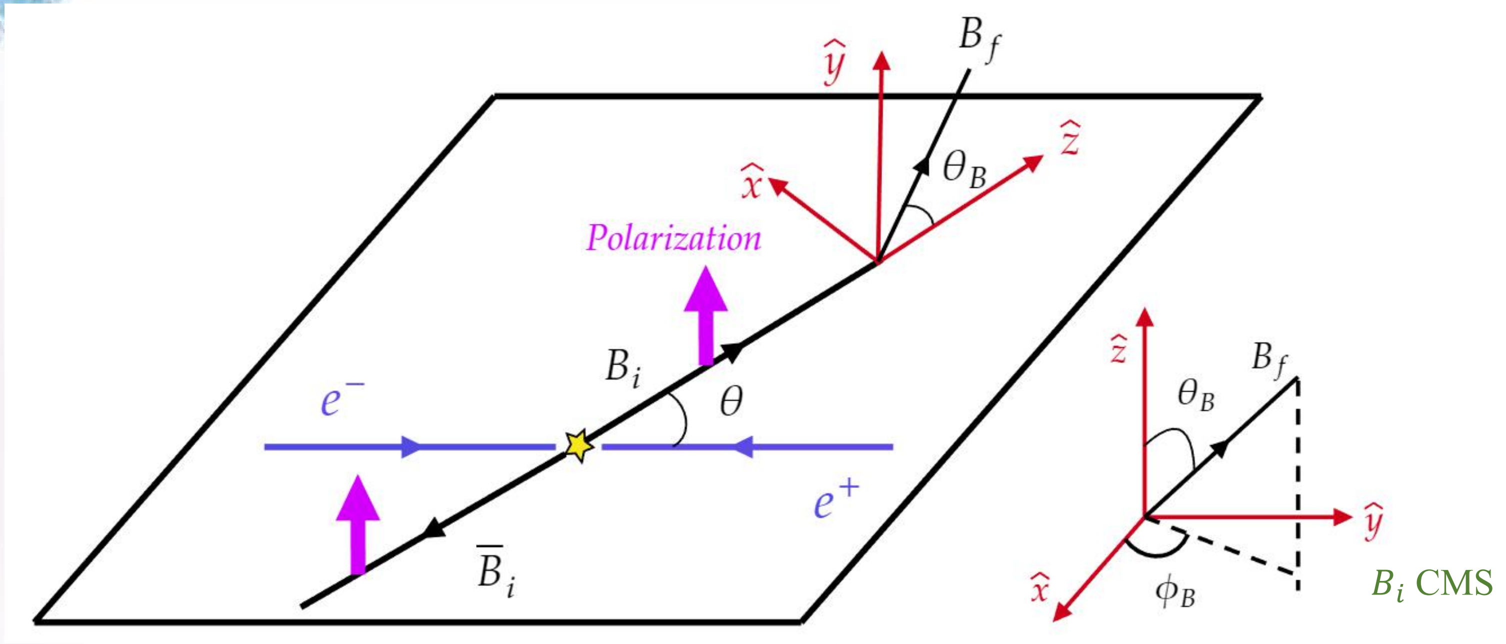
Experiments			# events	
B meson:	$O(1)$	discovered(2001)	10^3	B factory
K meson:	$O(10^{-3})$	discovered(1964)	10^6	Fix targets
D meson:	$O(10^{-4})$	discovered(2019)	10^8	LHCb
Hyperon:	$O(10^{-4})$	no evidence (10^{-2})	$O(10^8)$	Fix targets → **BESIII?**

Decay mode	$\mathcal{B}(\times 10^{-3})$	N_B $(\times 10^6)$	Detection Efficiency	Number of reconstructed
$J/\psi \to \Lambda\bar{\Lambda}$	1.61 ± 0.15	16.1 ± 1.5	40%	4500 X 10^3
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.29 ± 0.09	12.9 ± 0.9	25%	600 X 10^3
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.50 ± 0.24	15.0 ± 2.4	24%	640 X 10^3
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}^+$ (or c.c.)	0.31 ± 0.05	3.1 ± 0.5		
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$ (or c.c.)	1.10 ± 0.12	11.0 ± 1.2		
$J/\psi \to \Xi^0\bar{\Xi}^0$	1.20 ± 0.24	12.0 ± 2.4	14%	670 X 10^3
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.86 ± 0.11	8.6 ± 1.0	19%	810 X 10^3
$J/\psi \to \Xi(1530)^0\bar{\Xi}^0$	0.32 ± 0.14	3.2 ± 1.4		
$J/\psi \to \Xi(1530)^-\bar{\Xi}^+$	0.59 ± 0.15	5.9 ± 1.5		
$\psi(2S) \to \Omega^-\bar{\Omega}^+$	0.05 ± 0.01	0.15 ± 0.03		



$+\ \Omega^-(sss)$ spin-$\frac{3}{2}$

Polarized hyperon pairs produced in e^+e^- collisions



Two form factors are used to describe the production of hyperon pair: G_E, G_M

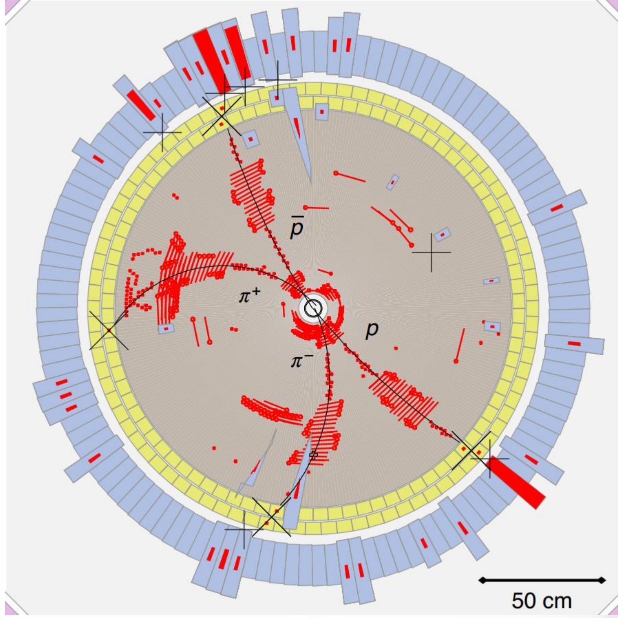
$$\alpha_\psi = \frac{s^2|G_M|^2-4m^2|G_E|^2}{s^2|G_M|^2+4m^2|G_E|^2}, \quad \frac{G_M}{G_E} = \left|\frac{G_M}{G_E}\right| e^{-i\Delta\Phi}$$

Polarization:

$$P_y(\cos\theta) = \frac{\sqrt{1-\alpha_\psi^2}\cos\theta\sin\theta}{1+\alpha_\psi\cos^2\theta}\sin(\Delta\Phi)$$

- Angular distribution of $\frac{d\Gamma}{d\Omega} \propto 1+\alpha_\psi\cos^2\theta$, $\alpha_\psi \in [-1.0,\ 1.0]$
- Unpolarized e^+e^- beams $\Rightarrow$ transverse polarized hyperon (if $\Delta\Phi \neq 0$):

$e^+e^- \rightarrow J/\psi \rightarrow \Lambda\bar{\Lambda}, \Lambda(\bar{\Lambda}) \rightarrow p\pi$



- Joint amplitude:

$$M = \frac{ie^2}{q^2} j_\mu \bar{u}(p_1)\left(F_1\gamma_\mu + \frac{F_2}{2m} p_\nu \sigma^{\nu\mu}\gamma_5\right) v(p_2)$$

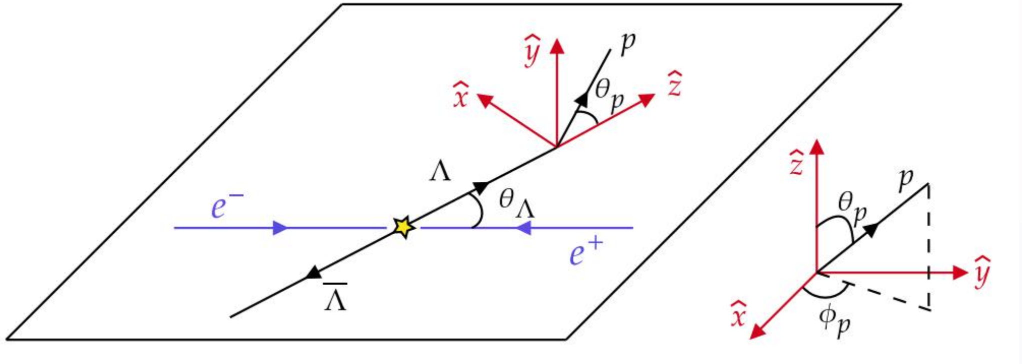
- Differential cross section:

$$d\sigma \sim 1 + \alpha_\psi \cos^2\theta_\Lambda + (\alpha_\psi + \cos^2\theta_\Lambda) s_\Lambda^z s_{\bar{\Lambda}}^z + \sin^2\theta_\Lambda s_\Lambda^x s_{\bar{\Lambda}}^x - \alpha_\psi \sin^2\theta_\Lambda s_\Lambda^y s_{\bar{\Lambda}}^y + \sqrt{1-\alpha_\psi^2}\cos\Delta\Phi \sin\theta_\Lambda \cos\theta_\Lambda (s_\Lambda^x s_{\bar{\Lambda}}^z + s_\Lambda^z s_{\bar{\Lambda}}^x) + \sqrt{1-\alpha_\psi^2}\sin\Delta\Phi \sin\theta_\Lambda \cos\theta_\Lambda (s_\Lambda^y + s_{\bar{\Lambda}}^y)$$

POLARIZATIONS

SPIN CORRELATIONS

- The spin vector of Λ is denoted by $\boldsymbol{s}_\Lambda$
- Only $< s^y >$ could be non-zero, if $\sin\Delta\Phi \neq 0$



Nuovo Cim. A 109, 241 (1996)
Phys. Rev.185 D 75, 074026 (2007)
Nucl. Phys. A190 771, 169 (2006)
Phys. Lett. B 772, 16(2017)

$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}, \Lambda(\bar{\Lambda}) \to p\pi$

BESIII has publish 2 works based on 1.3 billion and 10 billion J/ψ data sample:

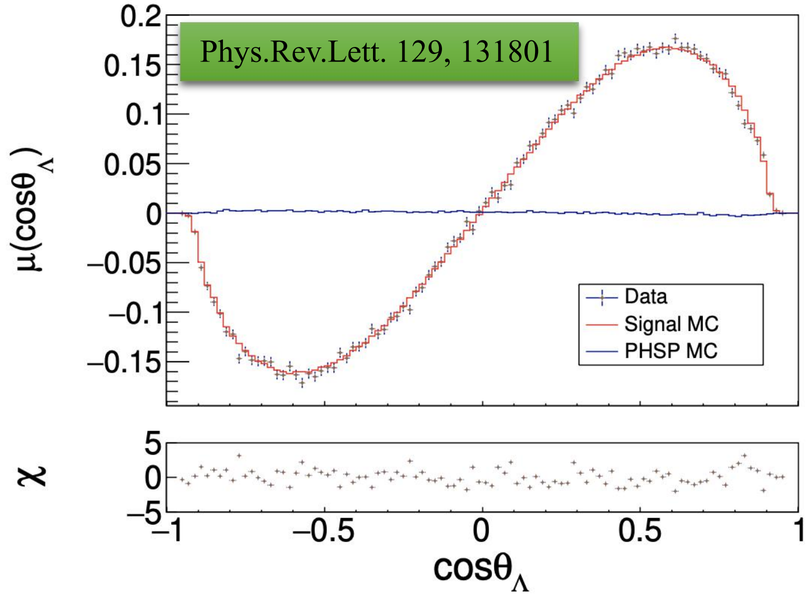
[1] 1.3 billion: Nature Phys.15(2019)631

[2] 10 billion: Phys.Rev.Lett. 129 (2022) 13, 131801

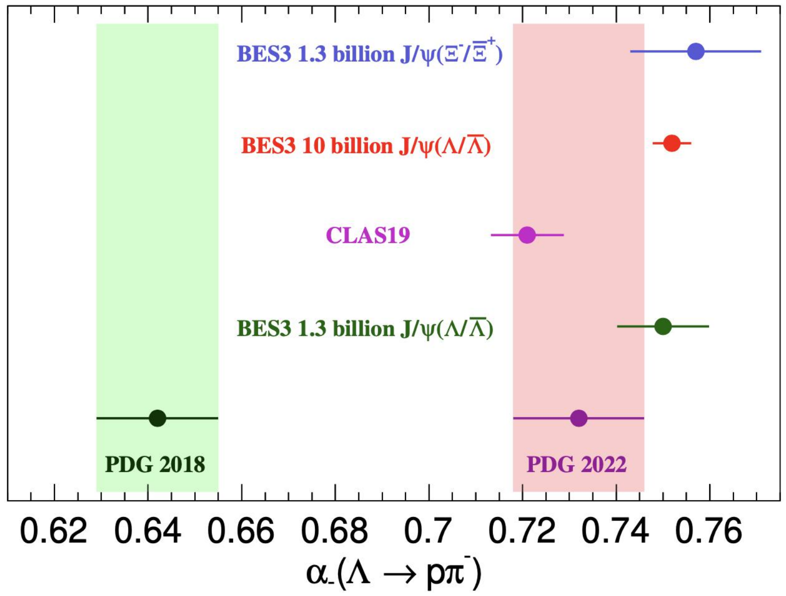
- Most precise values for Λ decay parameter
- One of the most precise CP test in the hyperon sector:

$$A_{CP} = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} = -0.0025 \pm 0.0046 \pm 0.0011$$

Standard mode prediction : $A_{CP} \sim 10^{-4}$ (PRD 34, 833 (1986))



Par.	This work	Previous results [12]
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0031$	$0.461 \pm 0.006 \pm 0.007$
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0066$	$0.740 \pm 0.010 \pm 0.009$
α_-	$0.7519 \pm 0.0036 \pm 0.0024$	$0.750 \pm 0.009 \pm 0.004$
α_+	$-0.7559 \pm 0.0036 \pm 0.0030$	$-0.758 \pm 0.010 \pm 0.007$
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0012$	$0.006 \pm 0.012 \pm 0.007$
α_{avg}	$0.7542 \pm 0.0010 \pm 0.0024$	-



$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+, \Xi^- \to \Lambda(\to p\pi^-)\pi^- + c.c.$

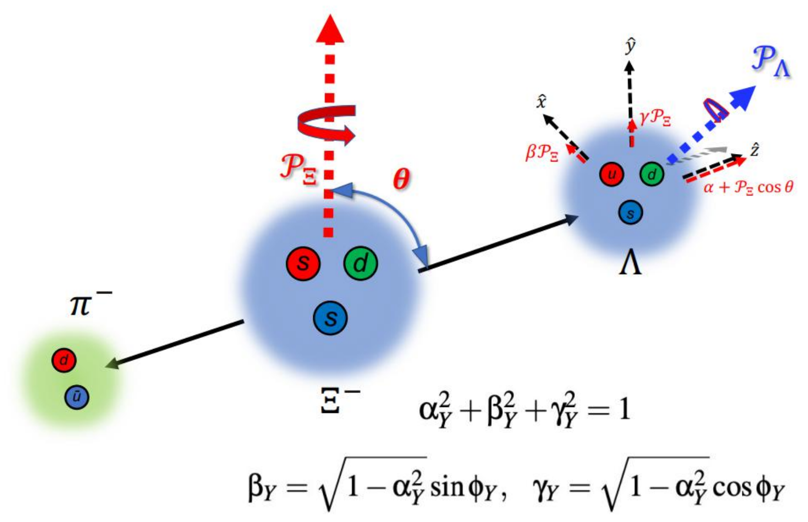
- For the sequential weak decays, the formula of sequential decays is:

$$\mathcal{W}(\boldsymbol{\xi}, \boldsymbol{\omega}) = \sum_{\mu,\bar{\nu}=0}^{3} C_{\mu\bar{\nu}} \sum_{\mu',\bar{\nu}'=0}^{3} a_{\mu\mu'}^{B_1} a_{\bar{\nu}\bar{\nu}'}^{\bar{B}_1} a_{\mu'0}^{B_2} a_{\bar{\nu}'0}^{\bar{B}_2}$$

PRD99(2019)056008
PRD100(2019)114005

- Angular distribution $d\Gamma \propto W(\xi, \omega)$
  - ξ: 9 kinematic variables, denoted by 9 helicity angles
  - $\omega = (\alpha_\psi, \Delta\Phi, \alpha_\Xi, \alpha_{\bar{\Xi}}, \phi_\Xi, \phi_{\bar{\Xi}}, \alpha_\Lambda, \alpha_{\bar{\Lambda}})$: 8 free parameters

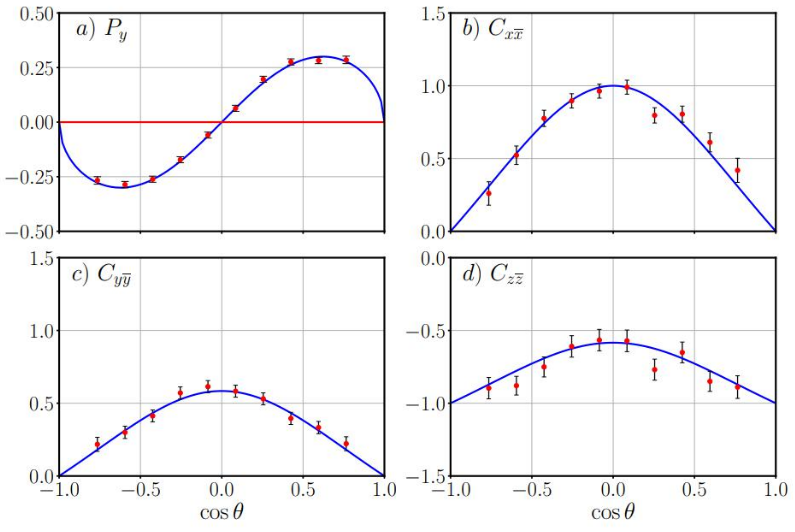
first measurement



$\alpha_Y^2 + \beta_Y^2 + \gamma_Y^2 = 1$

$\beta_Y = \sqrt{1-\alpha_Y^2}\sin\phi_Y, \quad \gamma_Y = \sqrt{1-\alpha_Y^2}\cos\phi_Y$

More parameters in sequential decay!



- Data sample: 1.3 billion J/ψ events.
- Final dataset: $73.2 \cdot 10^3$ events with 199 backgrounds.

$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+, \Xi^- \to \Lambda(\to p\pi^-)\pi^- + c.c.$

Nature 606 (2022) 7912, 64-69

Parameter	This work	Previous result
α_ψ	0.586±0.012±0.010	0.58±0.04±0.08
$\Delta\Phi$	1.213±0.046±0.016 rad	–
α_Ξ	−0.376±0.007±0.003	−0.401±0.010
ϕ_Ξ	0.011±0.019±0.009 rad	−0.037±0.014 rad
$\bar{\alpha}_\Xi$	0.371±0.007±0.002	–
$\bar{\phi}_\Xi$	−0.021±0.019±0.007 rad	–
α_Λ	0.757±0.011±0.008	0.750±0.009±0.004
$\bar{\alpha}_\Lambda$	−0.763±0.011±0.007	−0.758±0.010±0.007
$\xi_P-\xi_S$	$(1.2\pm3.4\pm0.8)\times10^{-2}$ rad	–
$\delta_P-\delta_S$	$(-4.0\pm3.3\pm1.7)\times10^{-2}$ rad	$(10.2\pm3.9)\times10^{-2}$ rad
A^Ξ_{CP}	$(6\pm13\pm6)\times10^{-3}$	–
$\Delta\phi^\Xi_{CP}$	$(-5\pm14\pm3)\times10^{-3}$ rad	–
A^Λ_{CP}	$(-4\pm12\pm9)\times10^{-3}$	$(-6\pm12\pm7)\times10^{-3}$
$\langle\phi_\Xi\rangle$	0.016±0.014±0.007 rad	

First measurement of the Ξ^- polarization in J/ψ decay

First direct and simultaneously measurement of the charged Ξ decay parameters

First measurement of weak phase difference in Ξ decay

Three independent *CP* tests

HyperCP: $\phi_{\Xi,HyperCP} = -0.042 \pm 0.011 \pm 0.011$

BESIII: $\langle\phi_\Xi\rangle$ =0.016±0.014±0.007

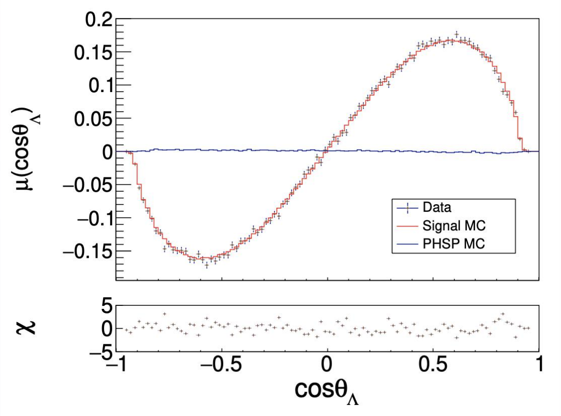
We obtain the same precision for ϕ as HyperCP with ***three orders of magnitude*** smaller data sample!

HyperCP: PRL 93(2004) 011802

Polarization behavior for different hyperons

$J/\psi \to \Lambda\bar{\Lambda}$

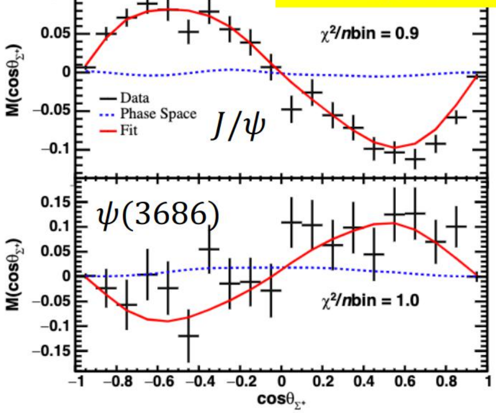
PRL129, 131801(2022)



$\Delta\Phi = (0.7521 \pm 0.0042 \pm 0.0066)\, rad$
$A_{CP} = -0.0025 \pm 0.0046 \pm 0.0012$

$\psi \to \Sigma^+\bar{\Sigma}^- \to p\pi^0\bar{p}\pi^0$

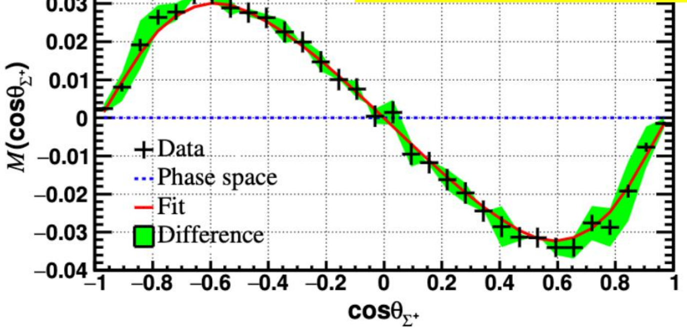
PRL125, 052004(2020)



$\Delta\Phi(J/\psi) = (-15.5 \pm 0.7 \pm 0.5)^\circ$
$\Delta\Phi(\psi(2S)) = (21.7 \pm 4.0 \pm 0.8)^\circ$
$A_{CP} = -0.004 \pm 0.037 \pm 0.010$

$J/\psi \to \Sigma^+\bar{\Sigma}^- \to n\pi^+\bar{p}\pi^0$

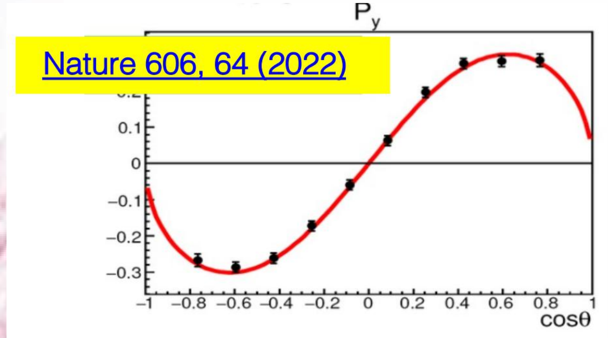
arXiv:2304.14655



$\Delta\Phi = (-0.277 \pm 0.004 \pm 0.004)\, rad$
$A_{CP} = -0.080 \pm 0.052 \pm 0.028$

$J/\psi \to \Xi^-\bar{\Xi}^+$

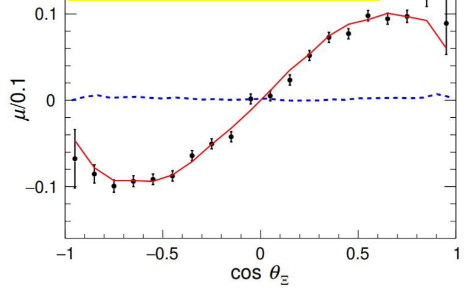
Nature 606, 64 (2022)



$\Delta\Phi = (1.213 \pm 0.046 \pm 0.016)\, rad$
$A_{CP} = -0.006 \pm 0.013 \pm 0.006$

$J/\psi \to \Xi^0\bar{\Xi}^0$

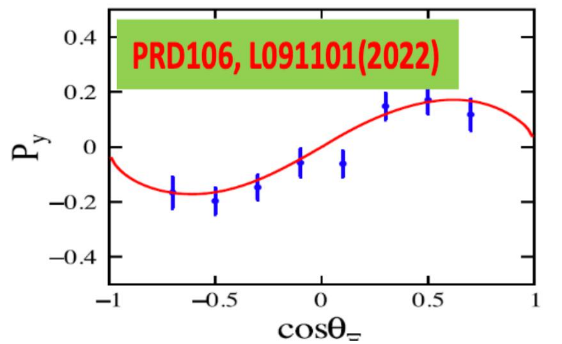
arXiv:2305.09218v1



$\Delta\Phi = (1.168 \pm 0.019 \pm 0.018)\, rad$
$A_{CP} = -0.0054 \pm 0.0065 \pm 0.0031$

$\psi(2S) \to \Xi^-\bar{\Xi}^+$

PRD106, L091101(2022)



$\Delta\Phi = (0.667 \pm 0.111 \pm 0.058)\, rad$
$A_{CP} = -0.015 \pm 0.051 \pm 0.010$

Summary of BESIII achievement

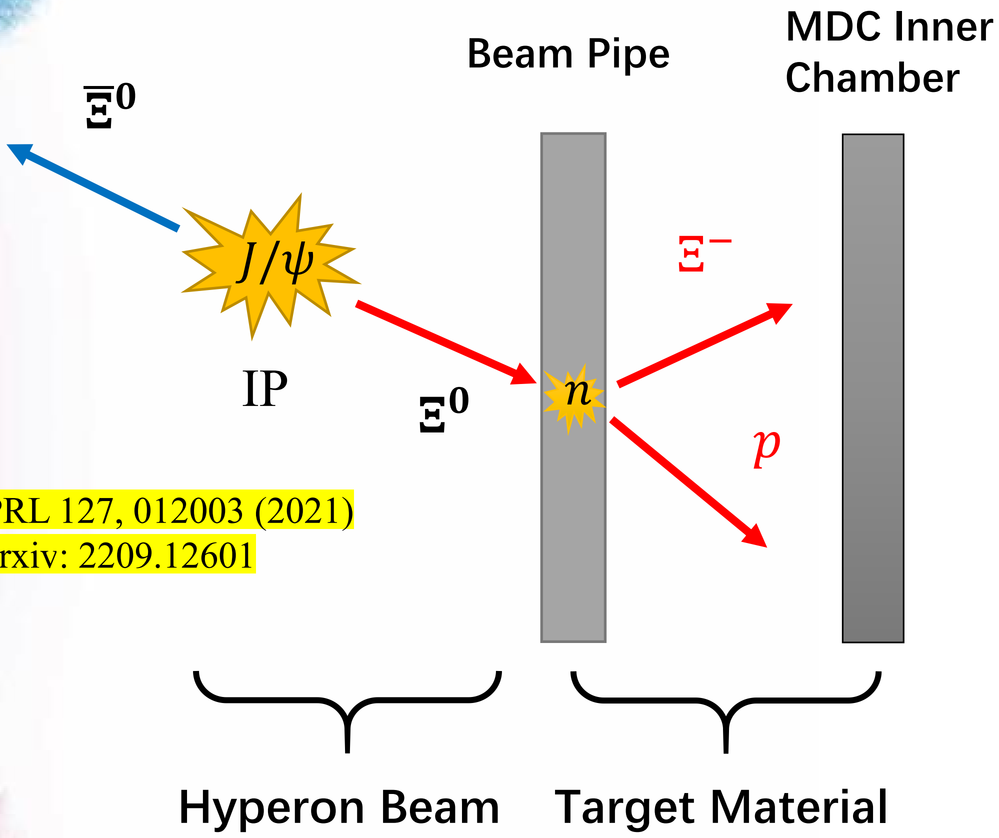
Parameters	$\Lambda\bar{\Lambda}$ (PRL 129, 131801(2022))	$\Sigma^+\bar{\Sigma}^-$ (PRL 125,052004(2020))	$\Xi^-\bar{\Xi}^+$ (Nature 606,64(2022))	$\Xi^0\bar{\Xi}^0$ (arXiv:2305.09218v1)
α_{Ξ^-/Ξ^0}	-	-	$-0.376 \pm 0.007 \pm 0.003$	$-0.3750 \pm 0.0034 \pm 0.0016$
$\alpha_{\bar{\Xi}^+/\bar{\Xi}^0}$	-	-	$0.371 \pm 0.007 \pm 0.002$	$0.3790 \pm 0.0034 \pm 0.0021$
ϕ_{Ξ^-/Ξ^0}	-	-	$0.011 \pm 0.019 \pm 0.009$	$0.0051 \pm 0.0096 \pm 0.0018$
$\phi_{\bar{\Xi}^+/\bar{\Xi}^0}$	-	-	$-0.021 \pm 0.019 \pm 0.007$	$-0.0053 \pm 0.0097 \pm 0.0019$
$A_{CP}(\Xi^-/\Xi^0)$	-	-	$0.006 \pm 0.013 \pm 0.006$	$-0.0054 \pm 0.0065 \pm 0.0031$
$\Delta\phi_{CP}(\Xi^-/\Xi^0)$	-	-	$-0.005 \pm 0.014 \pm 0.003$	$-0.0001 \pm 0.0069 \pm 0.0009$
$\alpha_{\Lambda/\Sigma^+}$	$0.7519 \pm 0.0036 \pm 0.0024$	$-0.998 \pm 0.037 \pm 0.009$	$0.757 \pm 0.011 \pm 0.008$	$0.7551 \pm 0.0052 \pm 0.0023$
$\alpha_{\bar{\Lambda}/\bar{\Sigma}^-}$	$-0.7559 \pm 0.0036 \pm 0.0030$	$0.990 \pm 0.037 \pm 0.011$	$-0.763 \pm 0.011 \pm 0.007$	$-0.7448 \pm 0.0052 \pm 0.0023$
$A_{CP}(\Lambda/\Sigma^+)$	$-0.0025 \pm 0.0046 \pm 0.0012$	$-0.004 \pm 0.037 \pm 0.010$	$-0.004 \pm 0.012 \pm 0.009$	$0.0069 \pm 0.0058 \pm 0.0018$

The most precise *CP* measurement at BESIII: $A_{CP}^{\Lambda} = -0.0025 \pm 0.0046 \pm 0.0012$

Systematic uncertainties are well controlled!

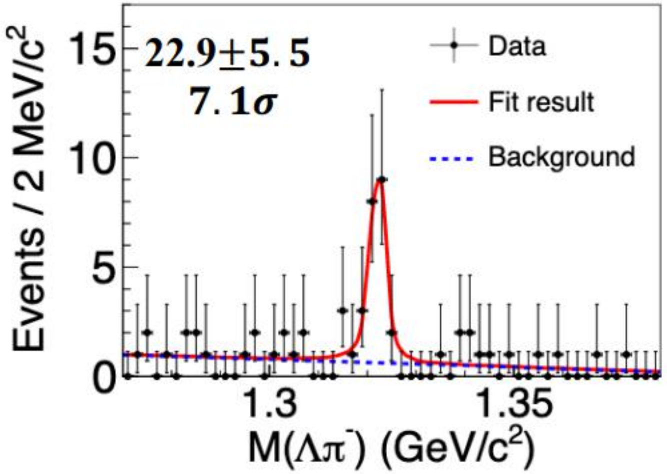
- Excellent performance of BESIII detectors.
- Data-driven method to study data-MC inconsistency.

Novel method to study hyperon-nucleon interaction



PRL 127, 012003 (2021)
arxiv: 2209.12601

arXiv:2304.13921(Accepted by PRL)



$\Xi^0 n \rightarrow \Xi^- p$ is observed for the first time

For Ξ^0 momentum is 0.818 GeV/c

$$\sigma(\Xi^0 n \rightarrow \Xi^- p) = (7.4 \pm 1.8_{\rm stat} \pm 1.5_{\rm sys})\ \text{mb}$$

(assuming effective number of reaction neutrons in ^{9}Be is 3)

$$\sigma(\Xi^0 + {}^9\text{Be} \rightarrow \Xi^- + p + {}^8\text{Be}) = (22.1 \pm 5.3_{\rm stat} \pm 4.5_{\rm sys})\ \text{mb},$$

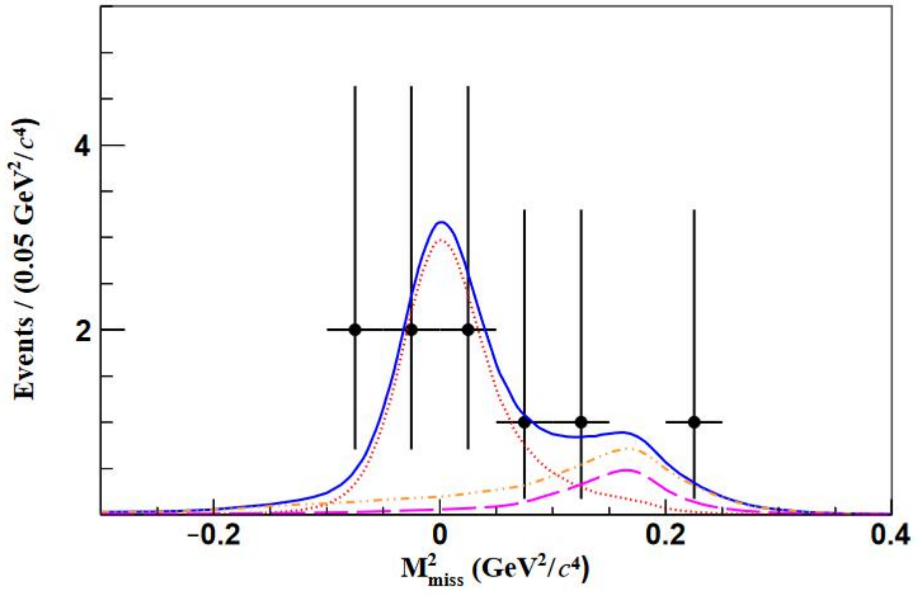
The first study of hyperon–nucleon interaction in electron–positron collisions!
More results are on the way.

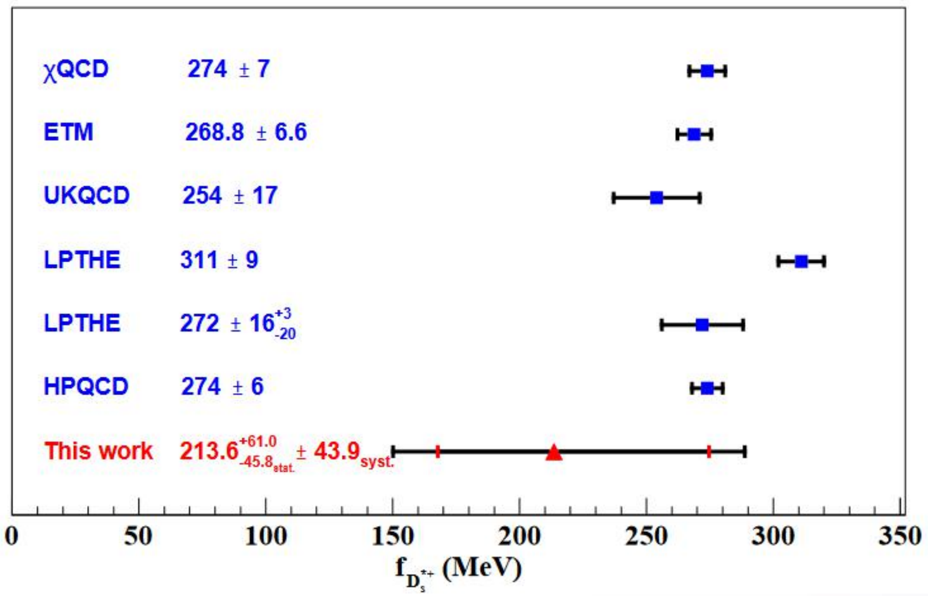
Content

First study of $D_s^{*+} \to e^+\nu_e$

arxiv: 2304.12159

- $D_s^{*+} \to e^+\nu_e$ first measured
- $Br(D_s^{*+} \to e^+\nu_e) = (2.1^{+1.2}_{-0.9}\,{}_{\text{stat}} \pm 0.2_{\text{syst}}) \times 10^{-5}$
- $f_{D_s^{*+}}|V_{cs}| = (207.9^{+59.4}_{-44.6}\,{}_{\text{stat}} \pm 42.7_{\text{syst}})\ \text{MeV}$
- $f_{D_s^{*+}} = (213.6^{+61.0}_{-45.8}\,{}_{\text{stat}} \pm 43.9_{\text{syst}})\ \text{MeV}$ (taking $|V_{cs}|$ extracted by the global fit in the SM)





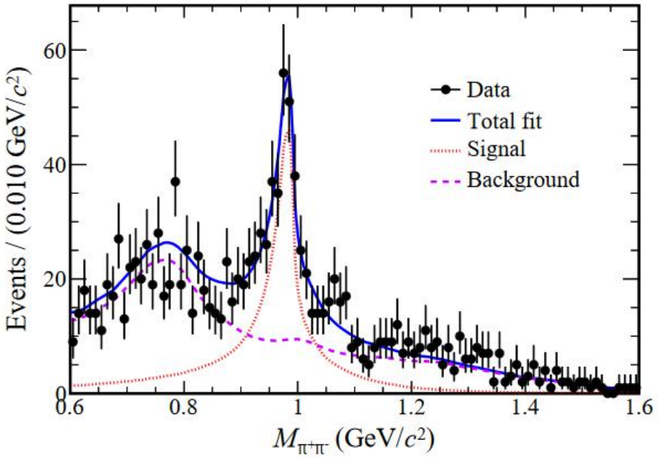
$f_0(980)$ in $D_s^+ \to \pi^+\pi^- e^+\nu_e$

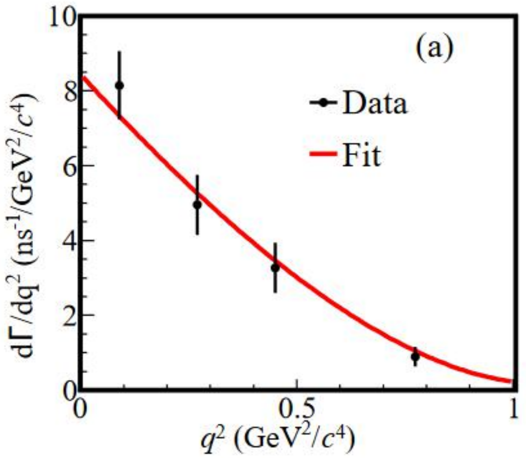
arxiv: 2303.12927

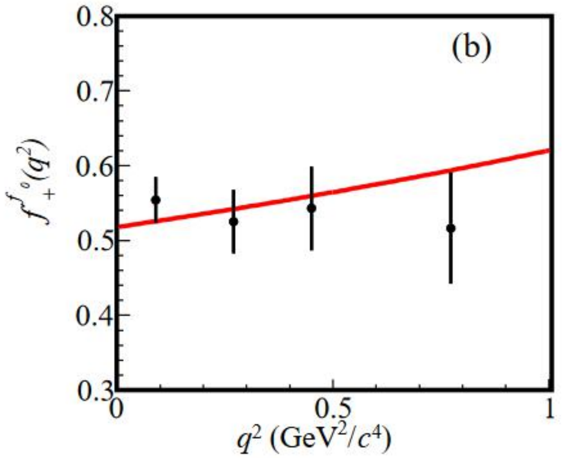
- $Br(D_s^+ \to f_0(980)e^+e^-) \times Br(f_0(980) \to \pi^+\pi^-) = (1.72 \pm 0.13_{\text{stat}} \pm 0.10_{\text{syst}}) \times 10^{-3}$
- Taking $f_0(980)$ as $sin\phi\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d}) + cos\phi s\bar{s}$ [EPL 90 (2010) 6, 61001Phys.Rev.D 80 (2009) 074030], $s\bar{s}$ is found to be dominant. Disagree with calculation [Phys.Rev.D 80 (2009) 074030] based on CLEO result [Phys.Rev.D 80 (2009) 052007]
- $f_+^{f_0}(0)|V_{cs}| = 0.504 \pm 0.017_{\text{stat}} \pm 0.035_{\text{syst}}$
- $f_+^{f_0}(0) = 0.518 \pm 0.018_{\text{stat}} \pm 0.036_{\text{syst}}$ (taking $|V_{cs}| = 0.97349 \pm 0.00016$)

large uncertainty due to the ϕ

	This work	CLFD [6]	DR [6]	QCDSR [7]	QCDSR [8]	LCSR [9]	LFQM [11]	CCQM [12]
$f_+^{f_0}(0)$	$0.518 \pm 0.018_{\text{stat}} \pm 0.036_{\text{syst}}$	0.45	0.46	0.50 ± 0.13	0.48 ± 0.23	0.30 ± 0.03	0.24 ± 0.05	0.39 ± 0.02
Difference (σ)	—	—	—	0.1	0.2	4.3	4.3	2.8
ϕ in theory	—	$(32 \pm 4.8)^\circ$	$(41.3 \pm 5.5)^\circ$	35°	$(8^{+21}_{-8})^\circ$	—	$(56 \pm 7)^\circ$	31°

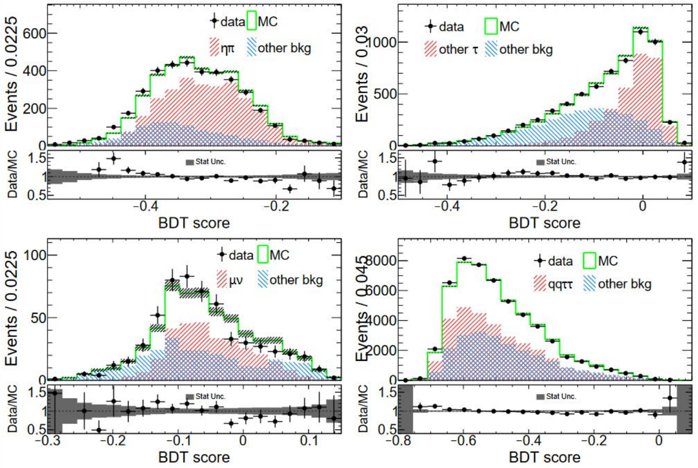


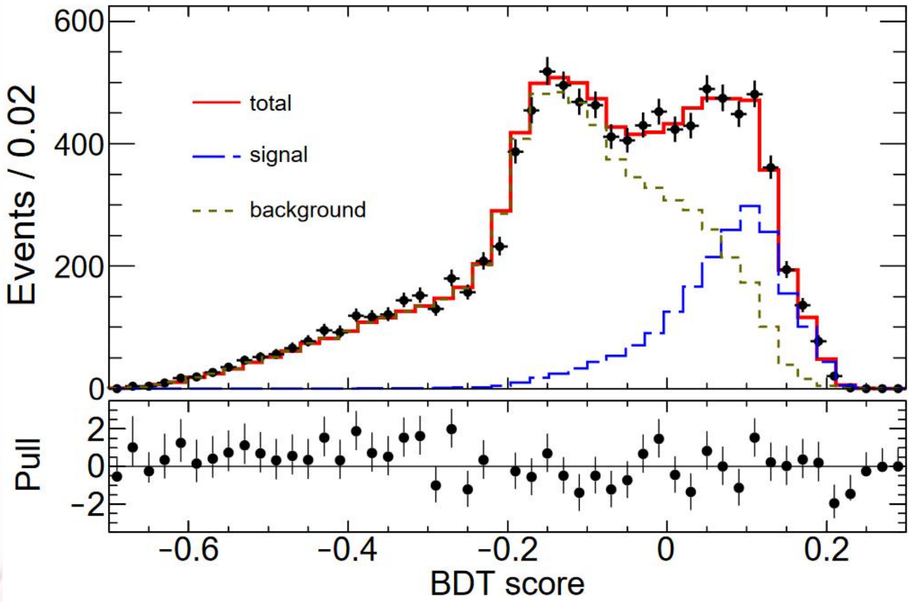




Further improvement on $D_s^+ \to \tau^+\nu_\tau$

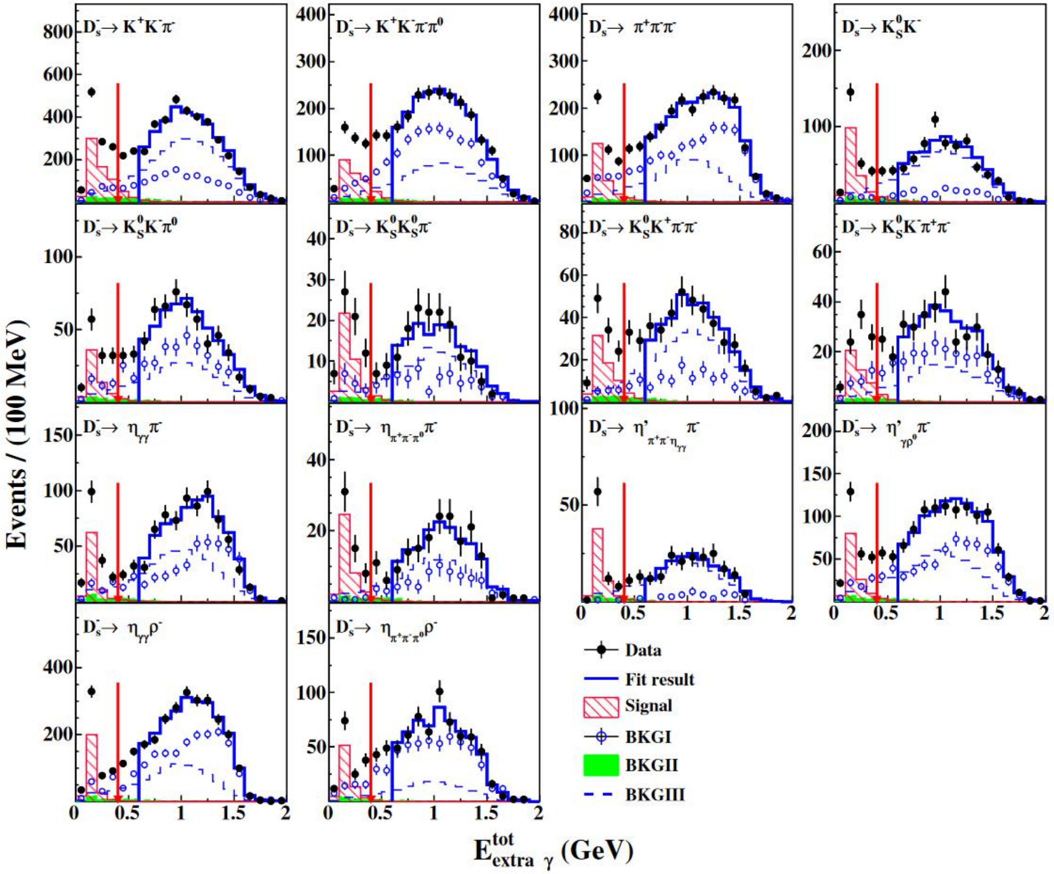
$D_s^+ \to \tau^+\nu_\tau, \tau^+ \to \pi^+\bar{\nu}_\tau$ arXiv:2303.12600



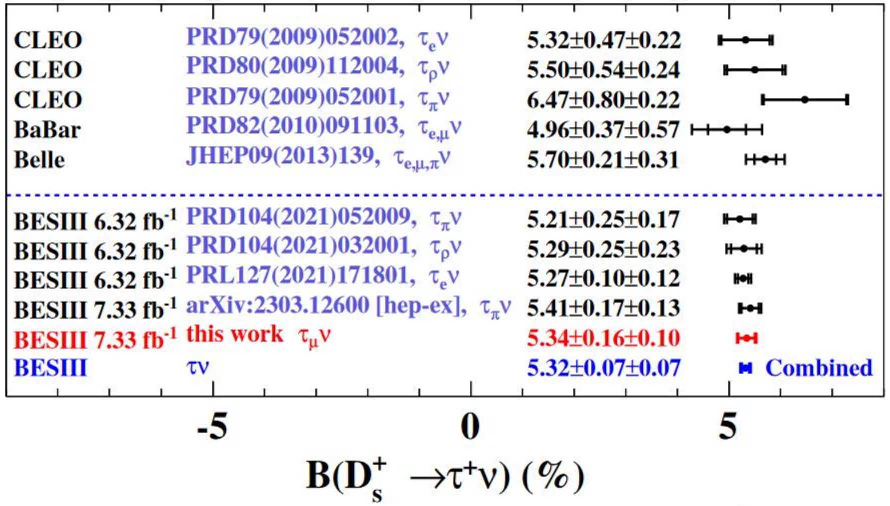


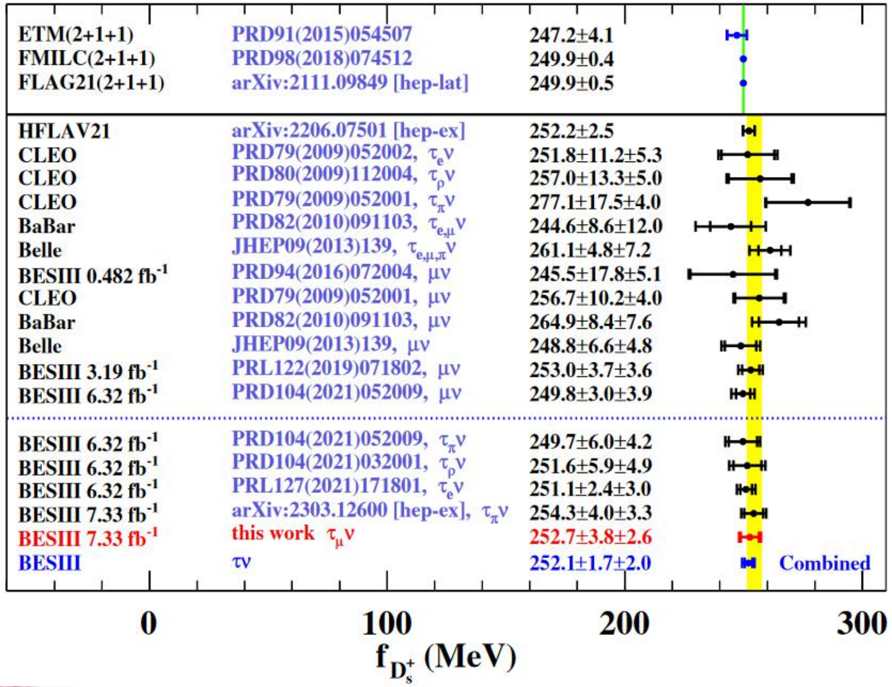
$D_s^+ \to \tau^+\nu_\tau, \tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$ arXiv:2303.12468

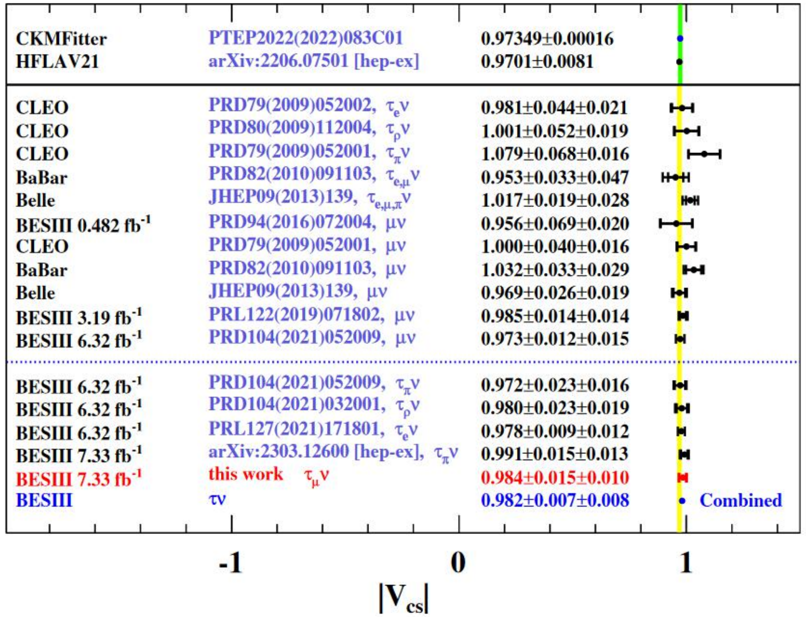
7.33 fb^{-1} data from 4.128 GeV to 4.226 GeV

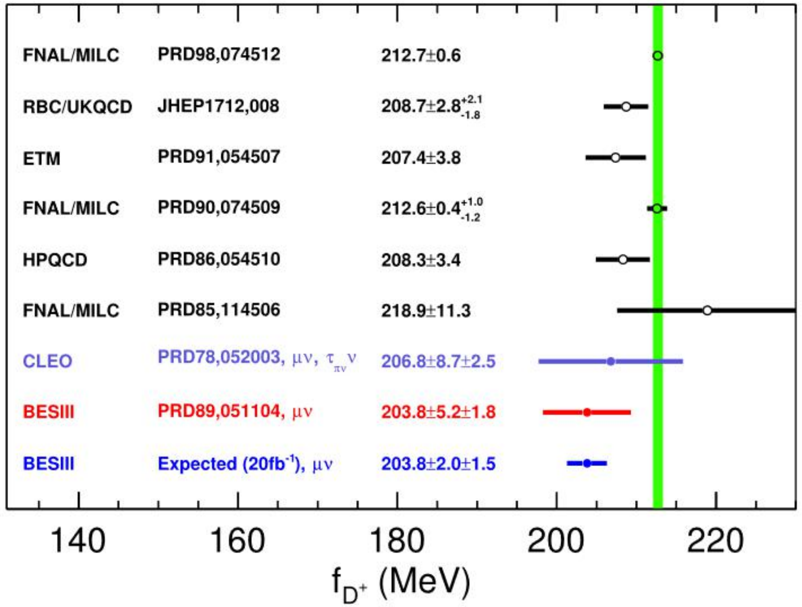


Further improvement on $D_s^+ \to \tau^+ \nu_\tau$

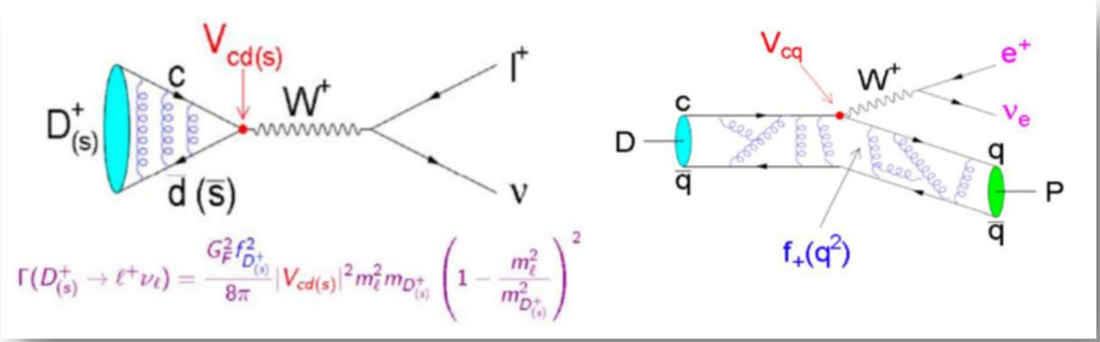






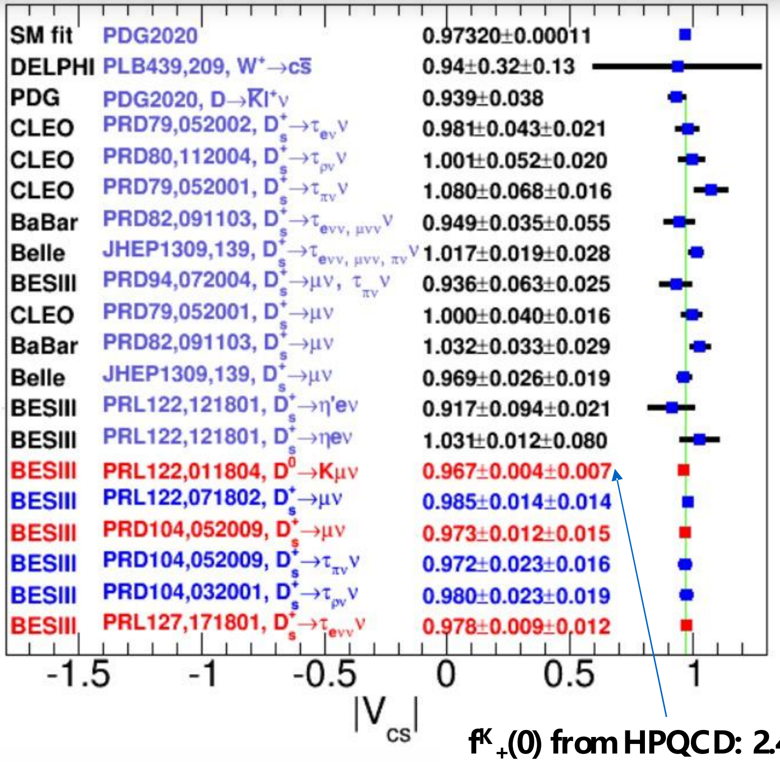


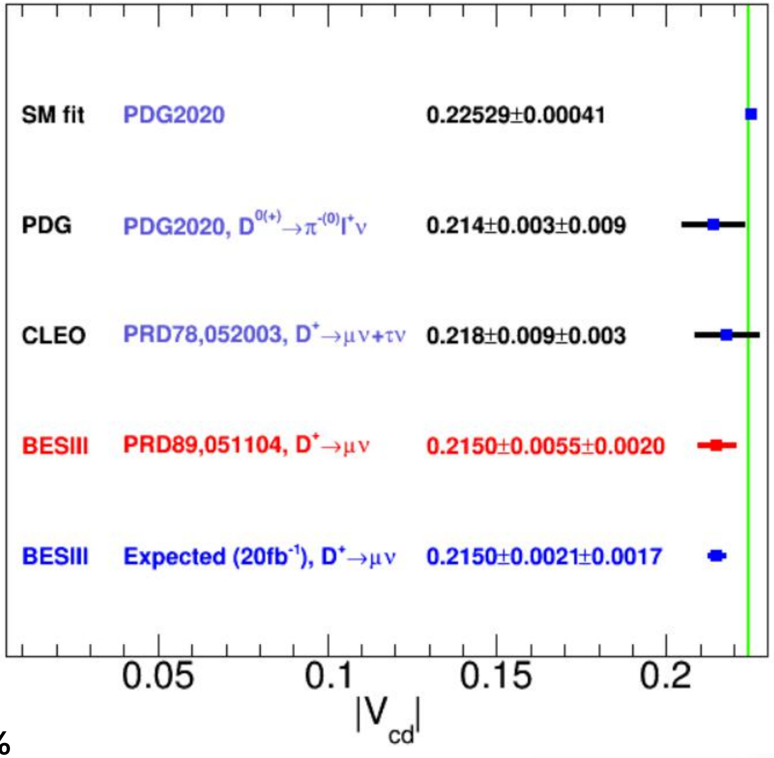
CKM matrix at BESIII



Fermilab Lattice and MILC, arXiv:2212.12648

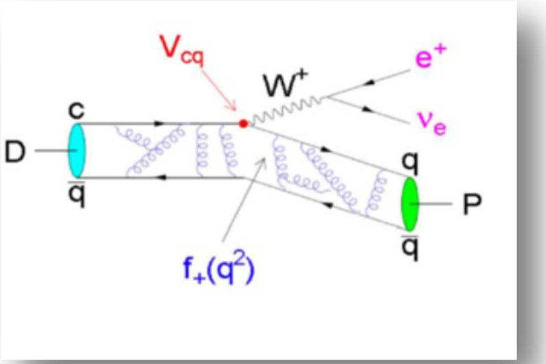
$$|V_{cd}|^{D\to\pi\ell^+\nu} = 0.2238(11)^{\rm Expt}(15)^{\rm QCD}(04)^{\rm EW}(02)^{\rm SIB}[22]^{\rm QED},$$
$$|V_{cd}|^{D_s\to K e^+\nu} = 0.258(15)^{\rm Expt}(01)^{\rm QCD}[03]^{\rm QED},$$
$$|V_{cs}|^{D\to K\ell^+\nu} = 0.9589(23)^{\rm Expt}(40)^{\rm QCD}(15)^{\rm EW}(05)^{\rm SIB}[95]^{\rm QED},$$





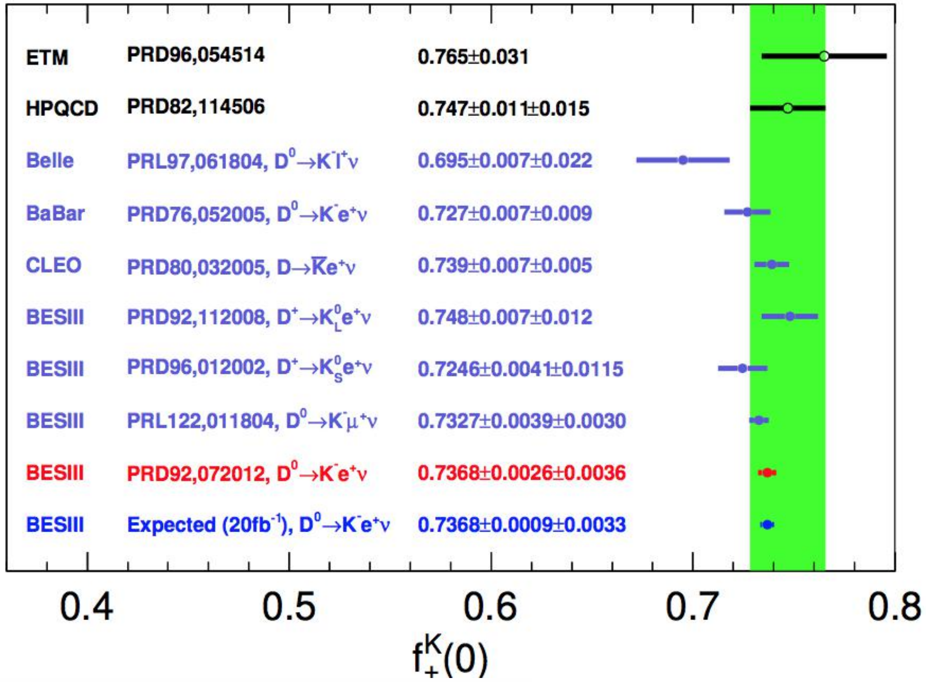
$f^K_+(0)$ from HPQCD: 2.4%→0.6%

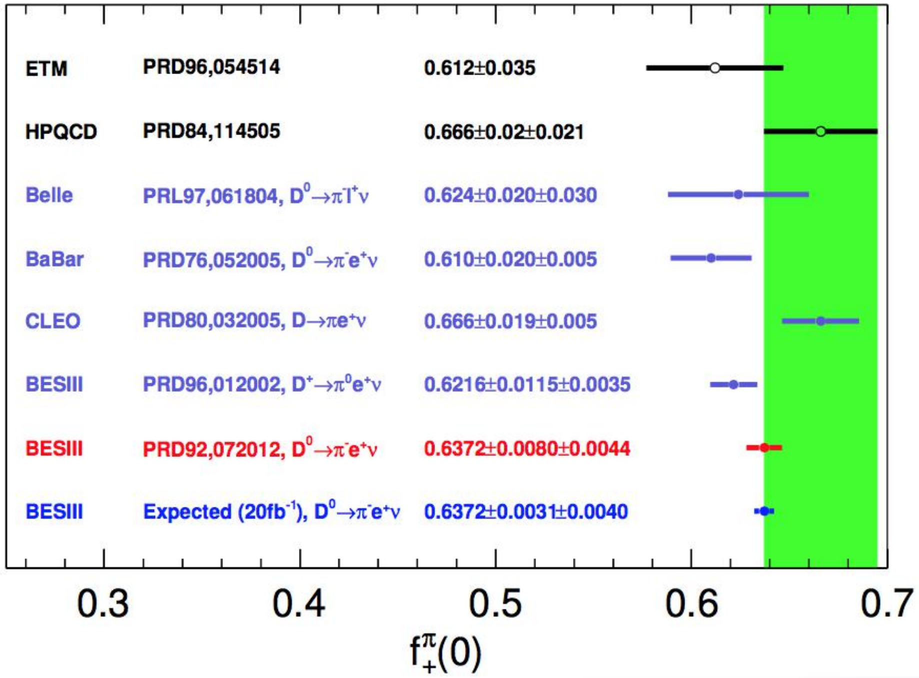
Form factors $f_+^{D\to h}$



Fermilab Lattice and MILC, arXiv:2212.12648

process	collaboration	$f_0(0)$
$D\to\pi$	FNAL/MILC	0.6300(51)
$D\to\pi$	ETMC 17	0.612(35)
$D\to K$	FNAL/MILC	0.7452(31)
$D\to K$	HPQCD 22	0.7441(40)
$D\to K$	HPQCD 21	0.7380(40)
$D\to K$	ETMC 17	0.765(31)
$D_s\to K$	FNAL/MILC	0.6307(20)



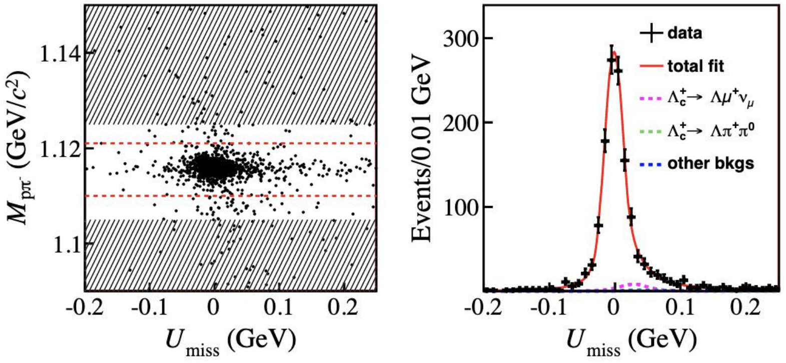


Λ_c semi-leptonic decay

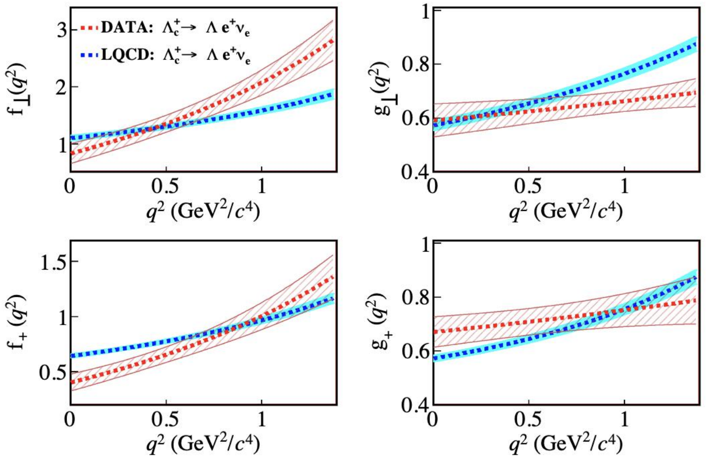
PRL129, 231803 (2022)

PRD106, 112010 (2022)

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

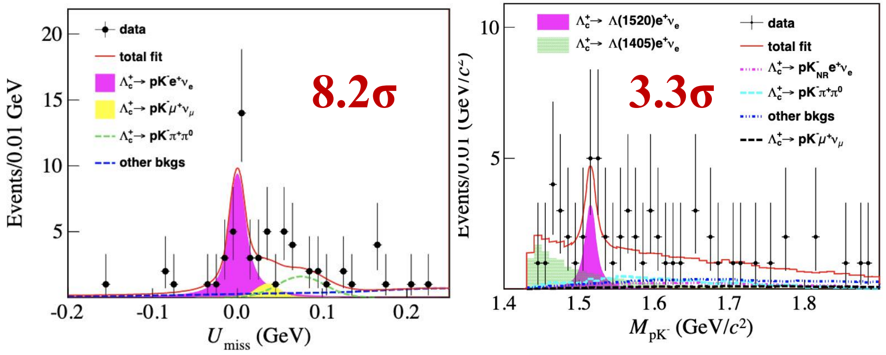


$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$



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

Observation of $\Lambda_c^+ \to pK^- e^+ \nu$



$B(\Lambda_c^+ \to pK^- e^+ \nu_e) = (0.88 \pm 0.17 \pm 0.07)\%$

$B(\Lambda_c^+ \to \Lambda(1405) e^+ \nu_e) = (1.87 \pm 0.84 \pm 0.18)\%$

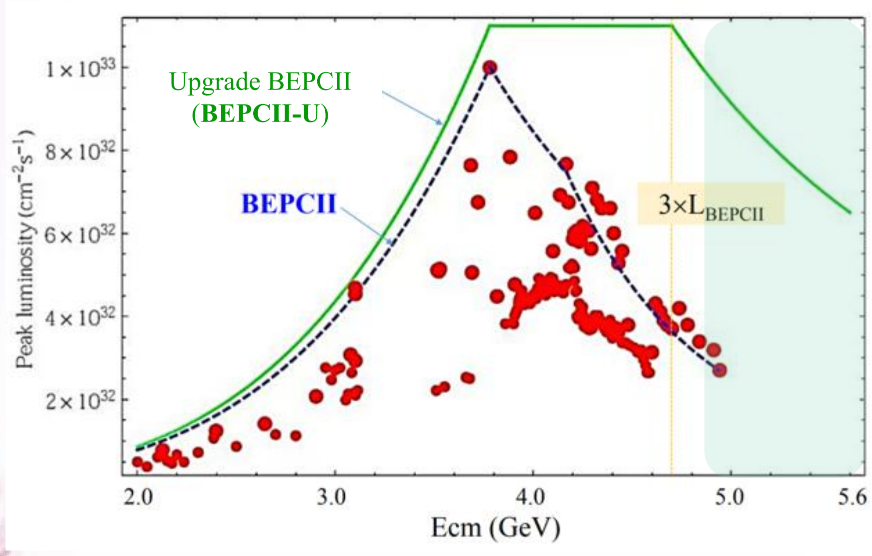
$B(\Lambda_c^+ \to \Lambda(1520) e^+ \nu_e) = (1.02 \pm 0.52 \pm 0.11)\%$

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

Content

BEPCII-Upgrade

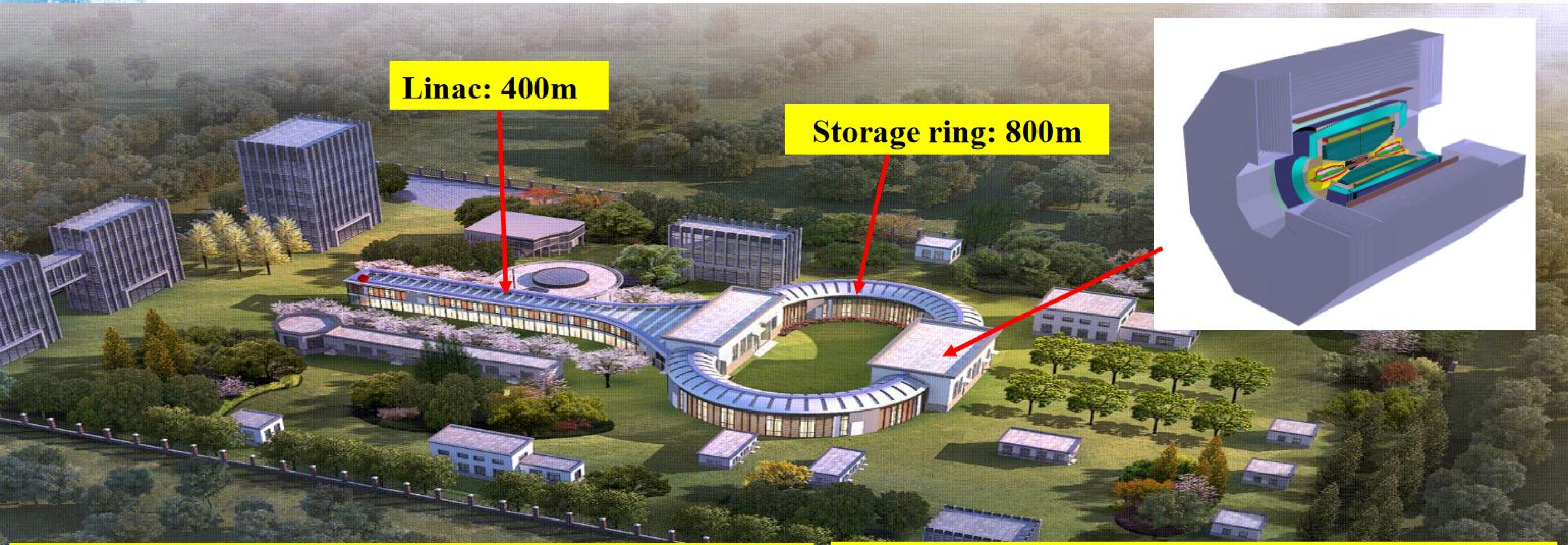
- ✓ An upgrade of BEPCII (**BEPCII-U**) has been approved in July 2021: **the optimized energy is 2.35 GeV with luminosity 3 times higher than current BEPCII and extend the maximum energy to 5.6 GeV**



	BEPCII	BEPCII-U
Lum [$10^{32}cm^{-2}s^{-1}$]	3.5	11
β_y^* [cm]	1.5	1.35
Bunch Current [mA]	7.1	7.5
Bunch Num	56	120
SR Power [kW]	110	250
$\xi_{y,\mathrm{lum}}$	0.029	0.033
Emittance [nmrad]	147	152
Coupling [%]	0.53	0.35
Bucket Height	0.0069	0.011
$\sigma_{z,0}$ [cm]	1.54	1.07
σ_z [cm]	1.69	1.22
RF Voltage [MV]	1.6	3.3

- ✓ Detailed studies of the known $Z_{c(s)}$ states and search for \`black swans\` in the higher energy region within a considerable amount of data sets.
- ✓ Extend precise R values to higher regions
- ✓ Cover all the ground-state charmed baryons: production & decays, CPV search

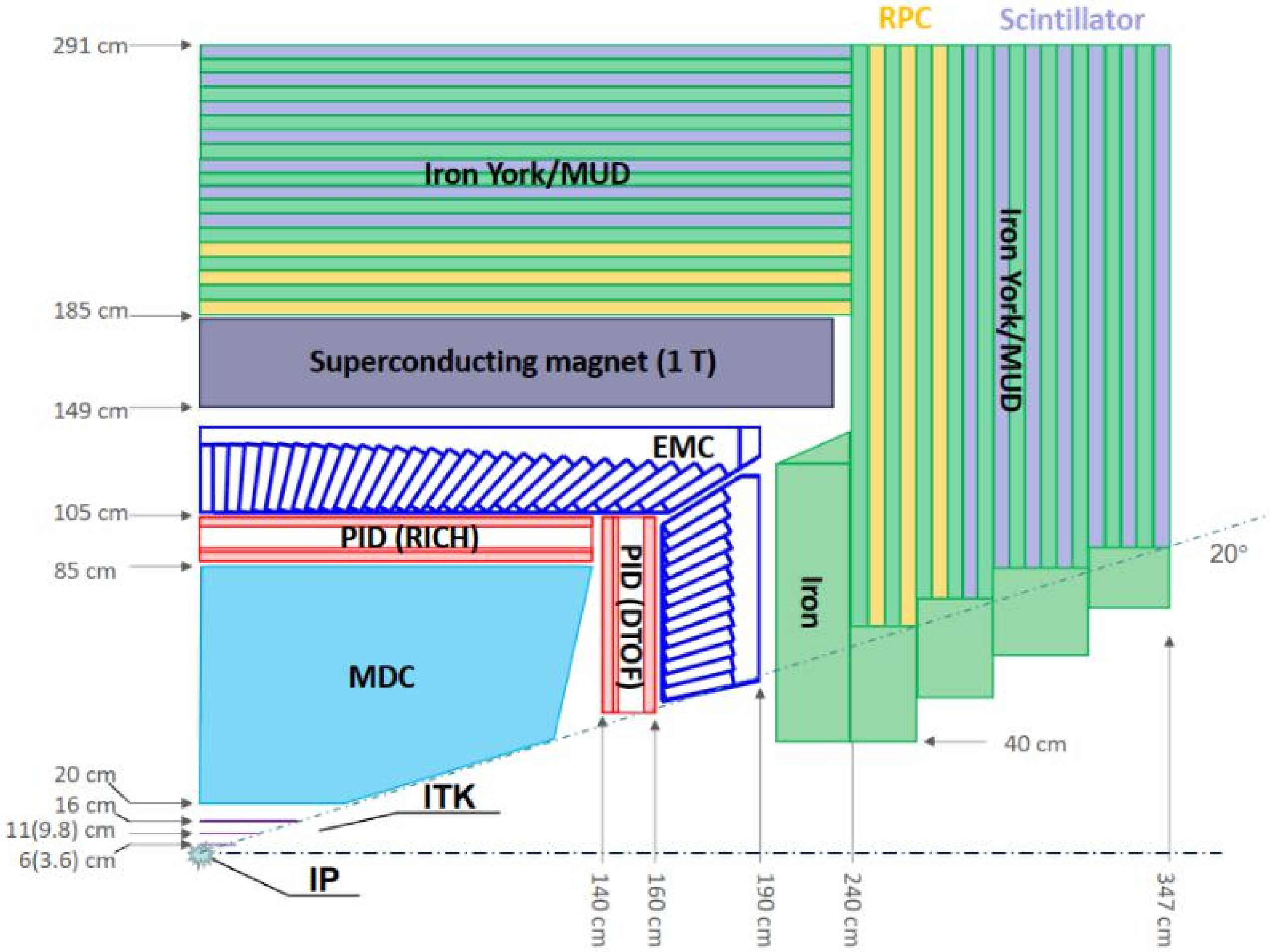
Super Tau Charm Facility (STCF) in China



- Peak luminosity >0.5×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
- Energy range E_{cm} = 2-7 GeV
- Potential to increase luminosity & realize beam polarization
- Total cost: 4.5B RMB

- 1 ab^{-1} data expected per year
- Rich physics program, unique for physics with *c* quark and τ leptons
- Important playground for study of QCD, exotic hadrons, flavor and search for new physics.

STCF detector



- **ITK:**
  - Material<$0.01X_0$, $\sigma_{xy} < 100\ \mu$m
- **MDC:**
  - Material<$0.05X_0$, $\sigma_{xy} < 130\ \mu$m
  - $\sigma(p)/p < 0.5\%$@1 GeV/c
  - $\sigma_{dE/dx} < 6\%$
- **PID:**
  - $3\sigma\ \pi/K$ seperation
  - PID efficiency>97% up to 2 GeV
- **EMC:**
  - $\sigma_E < 2.5\%$, σ_{pos}~4 mm, σ_t~300 ps @ 1 GeV
- **MUD:**
  - μ efficiency $> 95\%$ above 0.7 GeV with $\pi \to \mu$ misidentification rate $< 3\%$

QCD and hadron spectroscopy

Physics at STCF	Benchmark Processes	Key Parameters	
		BESIII	STCF
XYZ properties	$e^+e^- \to Y \to \gamma X, \eta X, \phi X$ $e^+e^- \to Y \to \pi Z_c, K Z_{cs}$	$N_{Y(4260)/Z_c/X(3872)}$ $\sim 10^6/10^6/10^4$	$N_{Y(4260)/Z_c/X(3872)}$ $\sim 10^{10}/10^9/10^6$
Pentaquarks Di-charmonium	$e^+e^- \to J/\psi p\bar{p}, \Lambda_c \bar{D}\bar{p}, \Sigma_c \bar{D}\bar{p}$ $e^+e^- \to J/\psi \eta_c, J/\psi h_c$	N/A	$\sigma(e^+e^- \to J/\psi p\bar{p})$~4 fb $\sigma(e^+e^- \to J/\psi c\bar{c})$~10 fb (prediction)
Hadron Spectroscopy	Excited $c\bar{c}$ and their transition, Charmed hadron spectroscopy, Light hadron spectroscopy	$N_{J/\psi/\psi(3686)/\Lambda_c}$ $\sim 10^{10}/10^9/10^6$	$N_{J/\psi/\psi(3686)/\Lambda_c}$ $\sim 10^{12}/10^{11}/10^8$
Hadron production (<2GeV) (Muon g-2)	$e^+e^- \to \pi^+\pi^-, \pi^+\pi^-\pi^0, K^+K^-$ $\gamma\gamma \to \pi^0, \eta^{(\prime)}, \pi^+\pi^-$	$\Delta a_\mu^{HVP} \sim 30 \times 10^{-11}$	$\Delta a_\mu^{HVP} < 10 \times 10^{-11}$
R value τ mass	$e^+e^- \to inclusive$ $e^+e^- \to \tau^+\tau^-$	$\delta R \sim 3\%$ $\Delta m_\tau \sim 0.12$ MeV	$\delta R \sim 1\%$ $\Delta m_\tau \sim 0.012$ MeV(1 month scan)
Fragmentation functions	$e^+e^- \to (\pi, K, p, \Lambda, D) + X$ $e^+e^- \to (\pi\pi, KK, \pi K) + X$	$\Delta A^{Collins} \sim 0.02$	$\Delta A^{Collins} < 0.002$
Nucleon FFs	$e^+e^- \to B\bar{B}$ from threshold	$\delta R_{EM} \sim 3\% - 20\%$	$\delta R_{EM} \sim 1\% - 3\%$

Flavour physics and CPV

Physics at STCF	Benchmark Processes	Key Parameters	
		BESIII	STCF
CKM matrix	$D^+_{(s)} \to l^+\nu_l$, $D \to Pl^+\nu_l$	$\delta V_{cd/cs}$~1.5% $\delta f_{D/D_s}$~1.5%	$\delta V_{cd/cs}$~0.15% $\delta f_{D/D_s}$~0.15%
γ/ϕ_3 measurement	$D^0 \to K_s\pi^+\pi^-, K_sK^+K^-$ ...	$\Delta(\cos\delta_{K\pi})$ ~0.05 $\Delta(\delta_{K\pi})$ ~10°	$\Delta(\cos\delta_{K\pi})$ ~0.007 $\Delta(\delta_{K\pi})$ ~2°
$D^0 - \bar{D}^0$ mixing	$\psi(3770) \to (D^0\bar{D}^0)_{CP=-}$, $\psi(4140) \to \gamma(D^0\bar{D}^0)_{CP=+}$	Δx~0.2% Δy~0.2%	Δx~0.035% Δy~0.023%
Charm hadron decay	$D_{(s)}, \Lambda_c^+, \Sigma_c, \Xi_c, \Omega_c$ decay	$N_{D/D_s/\Lambda_c}$~$10^7/10^7/10^6$	$N_{D/D_s/\Lambda_c}$~$10^9/10^8/10^8$
γ polarization	$D^0 \to K_1e^+\nu_e$	$\Delta A'_{UD}$~0.2 ??	$\Delta A'_{UD}$~0.015
CPV in Hyperons	$J/\psi \to \Lambda\bar{\Lambda}, \Sigma\bar{\Sigma}, \Xi^-\bar{\Xi}^-, \Xi^0\bar{\Xi}^0$	ΔA_Λ~10^{-3}	ΔA_Λ~10^{-4}
CPV in τ	$\tau \to K_s\pi\nu$, EDM of τ $\tau \to \pi/K\pi^0\nu$ for polarized e^-	N/A	$\Delta A_{\tau\to K_s\pi\nu}$~$10^{-3}$ Δd_τ~5×10^{-19} (e cm)
CPV in Charm	$D^0 \to K^+K^-/\pi^+\pi^-$, $\Lambda_c \to pK^-\pi^+\pi^0$ ...	ΔA_D~10^{-2} ΔA_{Λ_c}~10^{-2}	ΔA_D~10^{-3} ΔA_{Λ_c}~10^{-3}
CPV, CPT in $K^0 - \bar{K}^0$ mixing	$J/\psi \to K^0K^-\pi^+$		$\eta_\pm$~10^{-3}, $\Delta\phi_\pm$~0.05°

Exotic decays and BSM

Physics at STCF	Benchmark Processes	BESIII (U.L. at 90% C.L.)	STCF (U.L. at 90% C.L.)
LFV decays	$\tau \to \gamma l, lll, lP_1P_2$ $J/\psi \to ll', D^0 \to ll'(l' \neq l)\ldots$	N/A $\mathcal{B}(J/\psi \to e\tau) < 1 \times 10^{-8}$	$\mathcal{B}(\tau \to \gamma\mu/\mu\mu\mu) < 12/1.5 \times 10^{-9}$ $\mathcal{B}(J/\psi \to e\tau) < 0.71 \times 10^{-9}$
LNV, BNV	$D^+_{(s)} \to l^+l^+X^-, J/\psi \to \Lambda_c e^-$, $B \to \bar{B}$.:.	$\mathcal{B}(J/\psi \to \Lambda_c e^-) < 10^{-8}$	$\mathcal{B}(J/\psi \to \Lambda_c e^-) < 10^{-11}$
Charge Symmetry Violation	$\eta' \to ll\pi^0, \eta' \to \eta ll\ldots$	$\mathcal{B}(\eta' \to ll/\pi^0 ll) < 1 \times 10^{-6}$	$\mathcal{B}(\eta' \to ll/\pi^0 ll) < 1.5/2.4 \times 10^{-9}$
FCNC	$D \to \gamma V, D^0 \to l^+l^-, e^+e^- \to D^*, \Sigma^+ \to pl^+l^-\ldots$	$\mathcal{B}(D^0 \to e^+e^-X) < 10^{-6}$	$\mathcal{B}(D^0 \to e^+e^-X) < 10^{-8}$
Dark photon millicharged	$e^+e^- \to (J/\psi) \to \gamma A'(\to l^+l^-)\ldots$ $e^+e^- \to \chi\bar{\chi}\gamma\ldots$	Mixing strength $\Delta\epsilon_{A'} \sim 10^{-2}$; $\Delta\epsilon_{\chi} \sim 10^{-2}$	Mixing strength $\Delta\epsilon_{A'} \sim 10^{-4}$; $\Delta\epsilon_{\chi} \sim 10^{-4}$

Content

Summary

- Abundant physics results has been presented during the 15 years (more than 500 papers now)
- Cover a large scope of physics topics:
  - The decay of charmonium states has been studied thoroughly and in detail
  - 26 new states has been discovered at BESIII, including charomiun(-like) states (X, Y, Z_c, Z_{cs}), light hadrons and higher excited baryons
  - Precision measurements of hyperon decay parameters, polarization and CP asymmetry
  - Hyperon-nucleus interaction
  - Precise measurement of the CKM matrix elements $|V_{cs}|/|V_{cd}|$, the form factor of D meson and Λ_c baryon
- Future goals:
  - BEPCII-Upgrade
  - STCF

THANKS

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