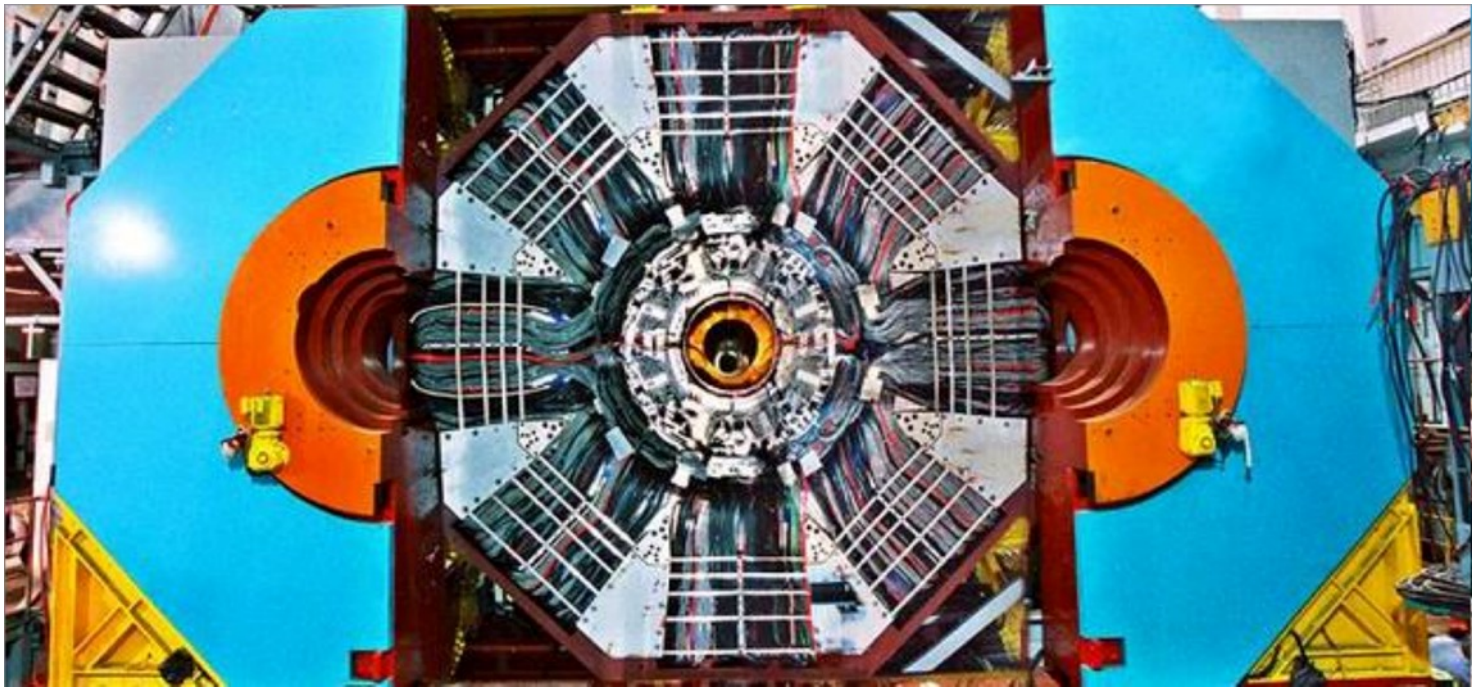

Recent results from the BESIII experiment

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University of Chinese Academy of Sciences (UCAS)

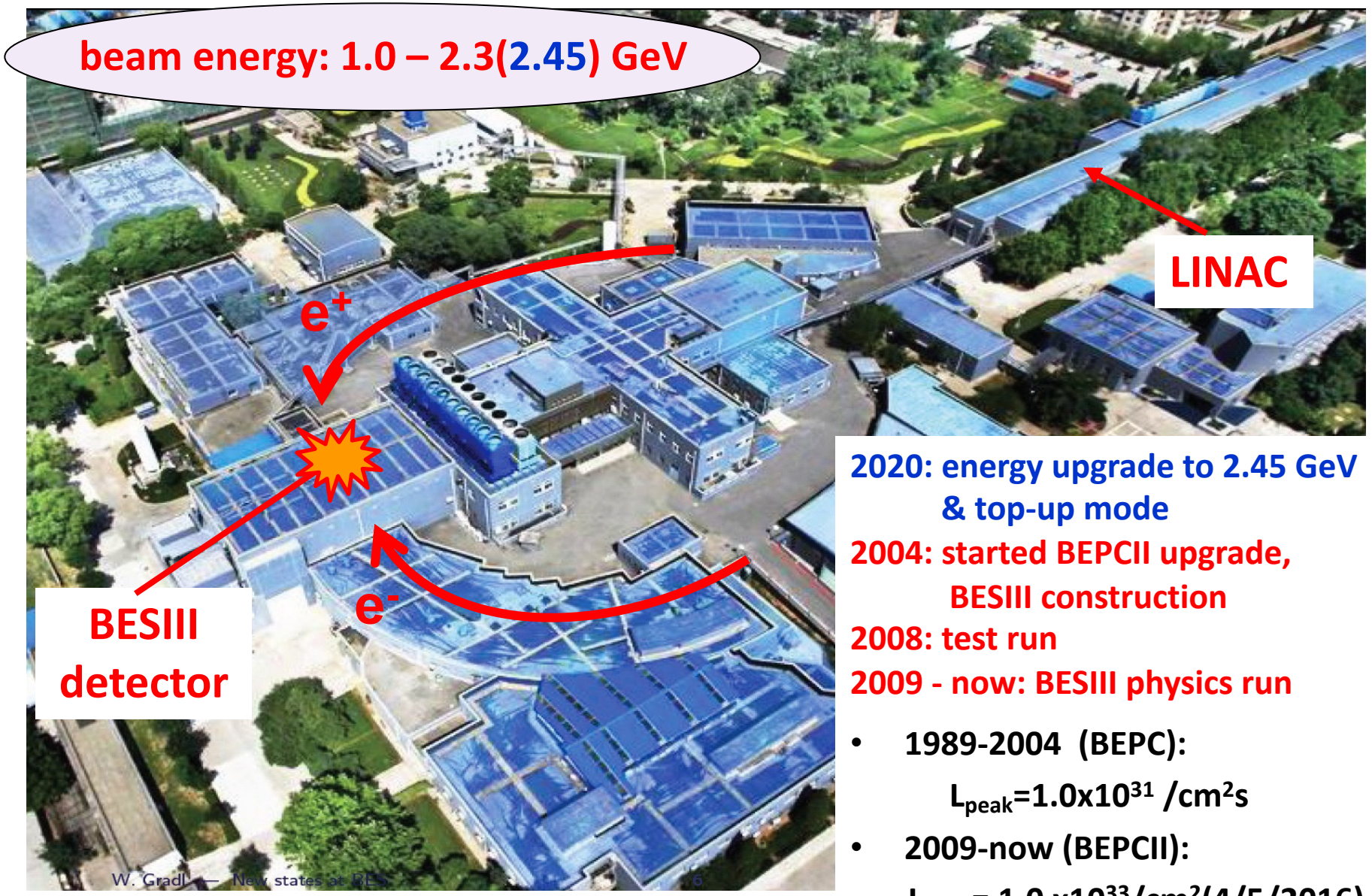
(On behalf of the BESIII collaboration)

Outline

- **Introduction**
- **Highlight on the recent results**
- **Prospects for the future**
- **Summary**

Disclaimer:
selective overview, not comprehensive; complementary to other BESIII talks

Beijing Electron Positron Collider (BEPCII)



2020: energy upgrade to 2.45 GeV & top-up mode

2004: started BEPCII upgrade, BESIII construction

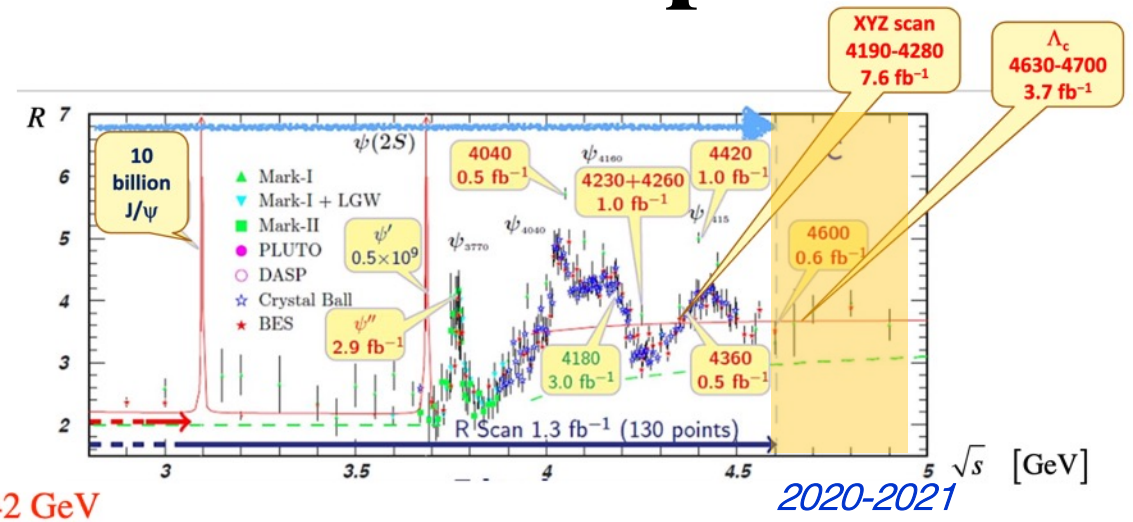
2008: test run

2009 - now: BESIII physics run

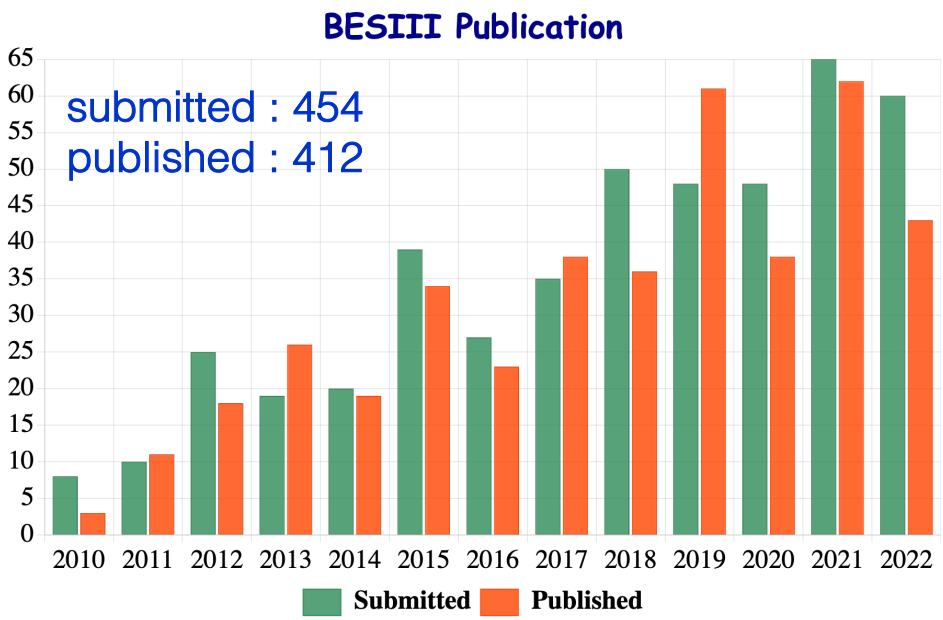
- 1989-2004 (BEPC): $L_{peak}=1.0\times10^{31}$ /cm^{2}s
- 2009-now (BEPCII): $L_{peak}= 1.0\times10^{33}$/cm^2(4/5/2016)

BESIII data sample

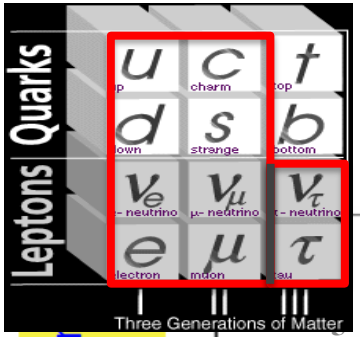
2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 pb^{-1} at $\psi(3770)$
2011: 2.9 fb^{-1} *(total)* at $\psi(3770)$
482 pb^{-1} at 4.01 GeV
2012: 0.45B *(total)* $\psi(2S)$
1.3B *(total)* J/ψ
2013: 1092 pb^{-1} at 4.23 GeV
826 pb^{-1} at 4.26 GeV
540 pb^{-1} at 4.36 GeV
10 × 50 pb^{-1} scan 3.81 — 4.42 GeV
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 $\psi(3770)$

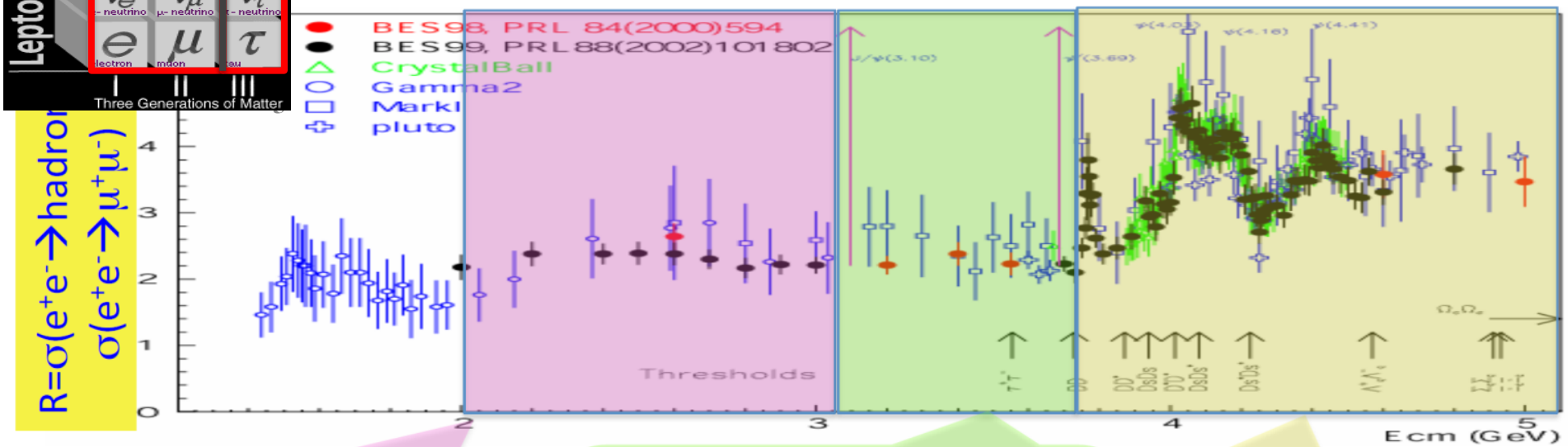


2020-2021



Physics at tau-charm Energy Region





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

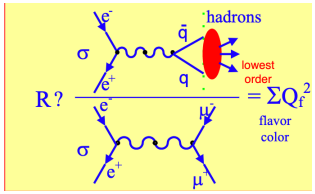
- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

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

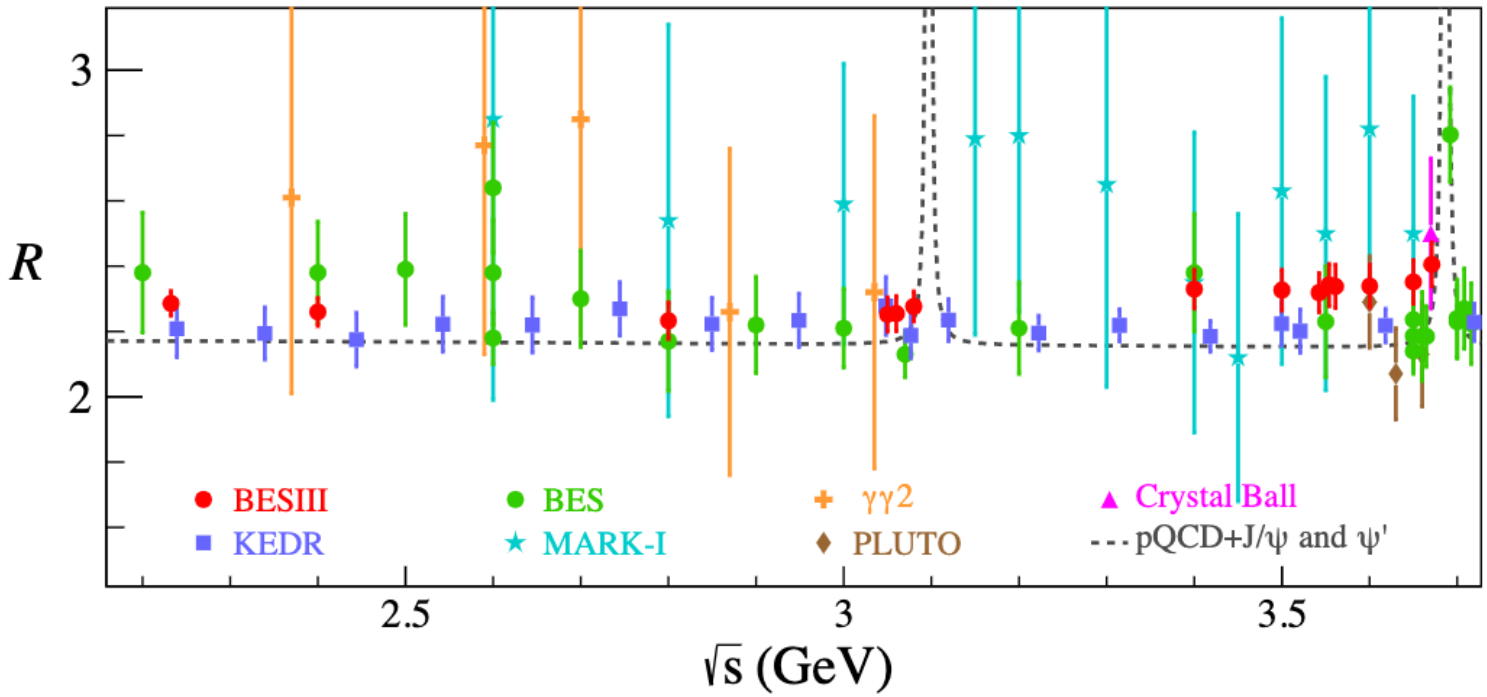
Updated *R* values at BESIII

PRL128, 062004 (2022)

- 14 fine-scan data points from 2.23-3.67 GeV
- Important inputs for SM-prediction of g-2

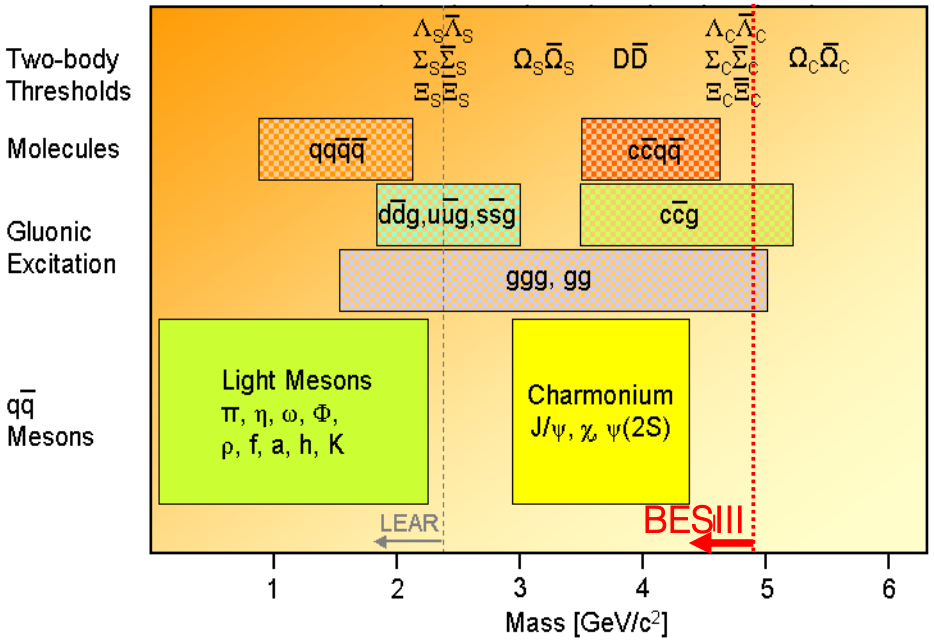


Comparing BESIII *R* values with previously published results:



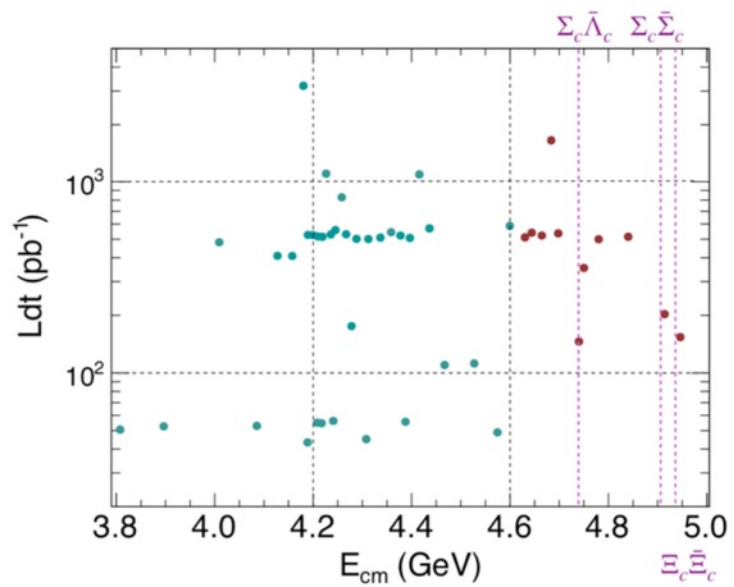
- **The accuracy is better than 2.6% below 3.1 GeV and 3.0% above.**
- **Larger than the pQCD prediction by 2.7σ between 3.4 ~ 3.6 GeV.**

Hadron Landscape



Hadron-physics challenges:

- Understanding of established states: precision spectroscopy
- Nature of exotic states: search and spectroscopy of unexpected states

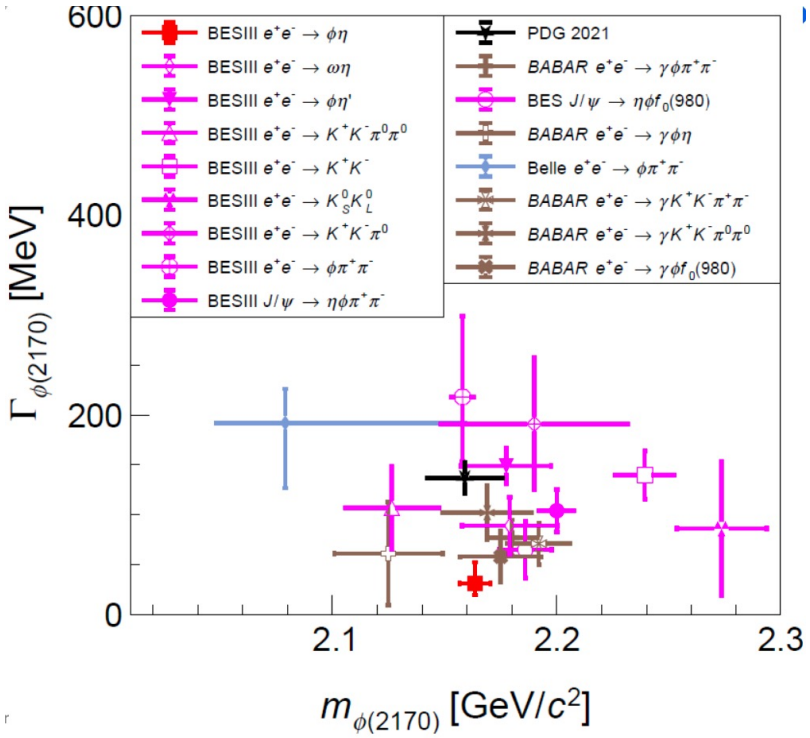


XYZ studies: about 23 /fb data above 3.8 GeV

At BESIII, two golden measures to study hadron spectroscopy, *esp.*, to search for exotics

- Light hadrons: charmonium radiative decays (act as spin filter) (**10 B J/ψ and 3 B ψ(2S)**)
- Heavy hadrons: direct production, radiative and hadronic transitions (**data above 3.8 GeV**)

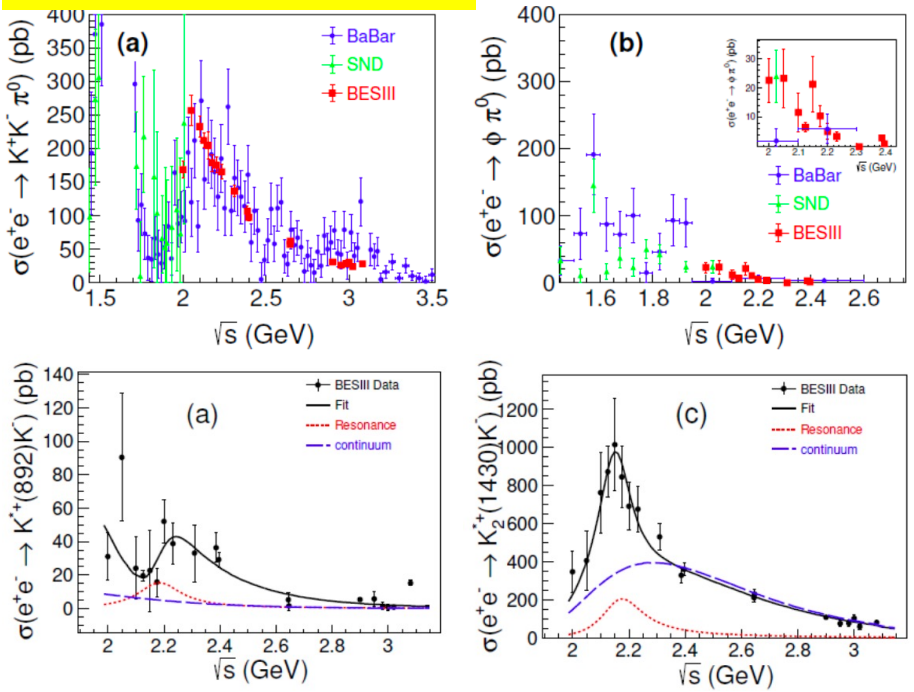
Y(2175) resonances



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

- M=2190±19±37 MeV/c^2, Γ=191±28±60 MeV from PWA of K*(892)K and K_2*(1430)K;

JHEP07, 045(2022)



$$\frac{\mathscr{B}(\phi(2170)\to K^{*+}(1430)K^-)}{\mathscr{B}(\phi(2170)\to K^{*+}(892)K^-)} = \frac{12.6\pm4.5}{(22.7\pm4.1)}$$

PWA of $J/\psi \to \gamma\eta\eta'$

arXiv:2202.00621, Accepted by PRL
arXiv:2202.00623, Accepted by PRD

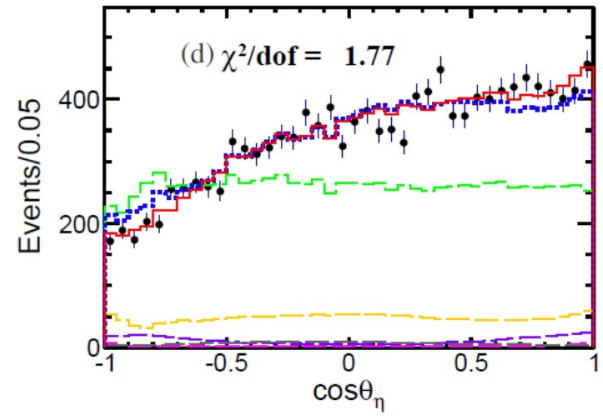
based on 10B J/ψ events

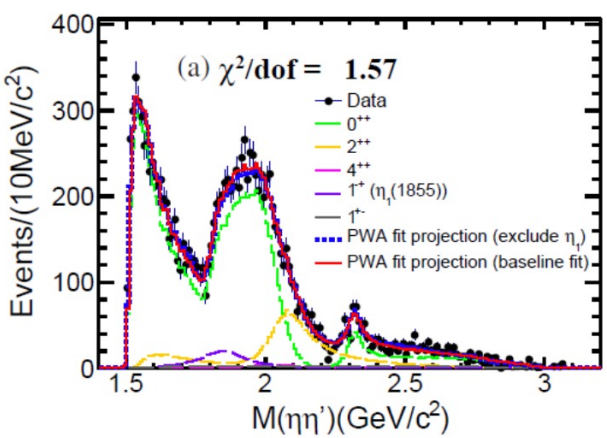
- The η' is reconstructed from $\gamma\pi^+\pi^-$ & $\eta\pi^+\pi^-$, η from $\gamma\gamma$
- Partial wave analysis of $J/\psi \to \gamma\eta\eta'$

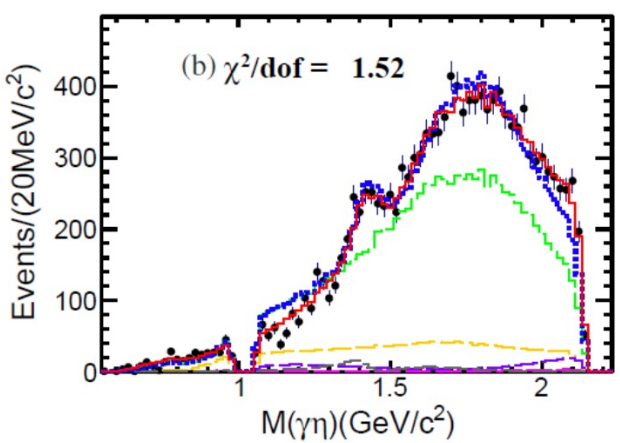
  Quasi two-body decay amplitudes in the sequential decay processes $J/\psi \to \gamma X, X \to \eta\eta'$ and $J/\psi \to \eta X, X \to \gamma\eta'$ and $J/\psi \to \eta' X, X \to \gamma\eta$ are constructed using the covariant tensor formalism[5]

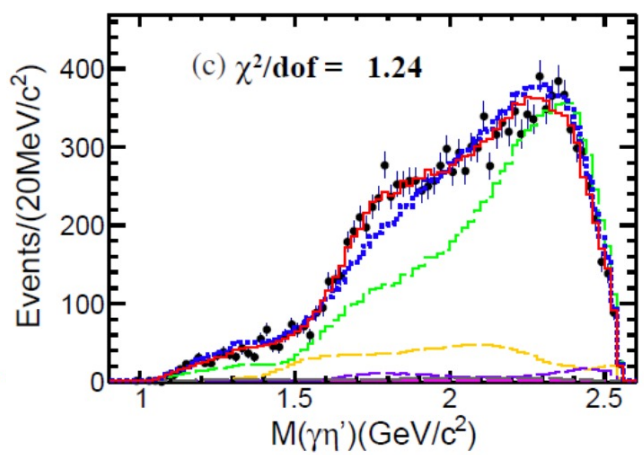
- All kinematically allowed known resonances with 0^{++}, 2^{++}, 4^{++} ($\eta\eta'$) and 1^{+-}, 1^{-+}($\gamma\eta^{(\prime)}$) are considered

  1^{-+} in $\eta\eta'$ is also considered (η/η' not identical particle)









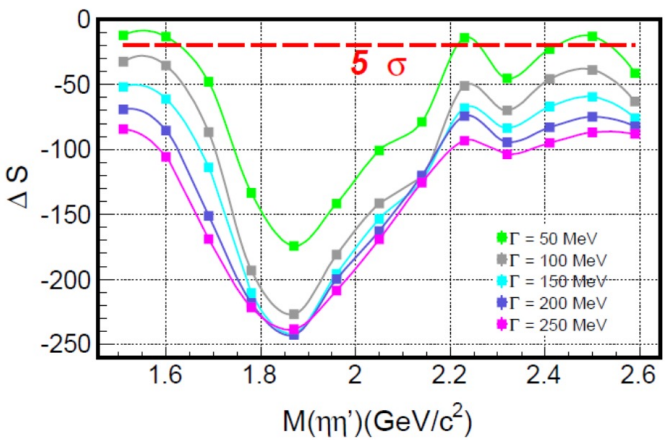
Observation of exotic isoscalar meson $\eta_1(1855)(1^{-+})$

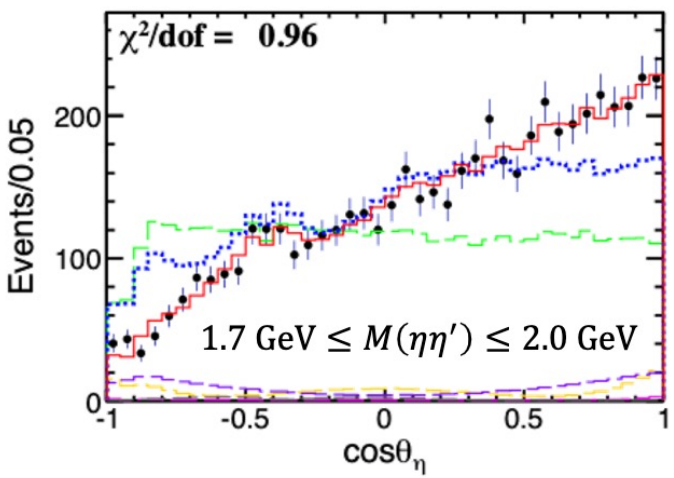
arXiv:2202.00621, Accepted by PRL
arXiv:2202.00623, Accepted by PRD

Decay mode	Resonance	M (MeV/c^2)	Γ (MeV)	$M_{\rm PDG}$ (MeV/c^2)	$\Gamma_{\rm PDG}$ (MeV)	B.F. ($\times 10^{-5}$)	Sig.
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_0(1500)$	1506	112	1506	112	$1.81\pm0.11^{+0.19}_{-0.13}$	$\gg30\sigma$
	$f_0(1810)$	1795	95	1795	95	$0.11\pm0.01^{+0.04}_{-0.03}$	11.1σ
	$f_0(2020)$	$2010\pm6^{+6}_{-4}$	$203\pm9^{+13}_{-11}$	1992	442	$2.28\pm0.12^{+0.29}_{-0.20}$	24.6σ
	$f_0(2330)$	$2312\pm7^{+7}_{-3}$	$65\pm10^{+3}_{-12}$	2314	144	$0.10\pm0.02^{+0.01}_{-0.02}$	13.2σ
	$\eta_1(1855)$	$1855\pm9^{+6}_{-1}$	$188\pm18^{+3}_{-8}$	-	-	$0.27\pm0.04^{+0.02}_{-0.04}$	21.4σ
	$f_2(1565)$	1542	122	1542	122	$0.32\pm0.05^{+0.12}_{-0.02}$	8.7σ
	$f_2(2010)$	$2062\pm6^{+10}_{-7}$	$165\pm17^{+10}_{-5}$	2011	202	$0.71\pm0.06^{+0.10}_{-0.06}$	13.4σ
	$f_4(2050)$	2018	237	2018	237	$0.06\pm0.01^{+0.03}_{-0.01}$	4.6σ
	0^{++} PHSP	-	-	-	-	$1.44\pm0.15^{+0.10}_{-0.20}$	15.7σ
$J/\psi \to \eta' X \to \gamma\eta\eta'$	$h_1(1415)$	1416	90	1416	90	$0.08\pm0.01^{+0.01}_{-0.02}$	10.2σ
	$h_1(1595)$	1584	384	1584	384	$0.16\pm0.02^{+0.03}_{-0.01}$	9.9σ

Hybrid?
Molecule?
Tetraquark?

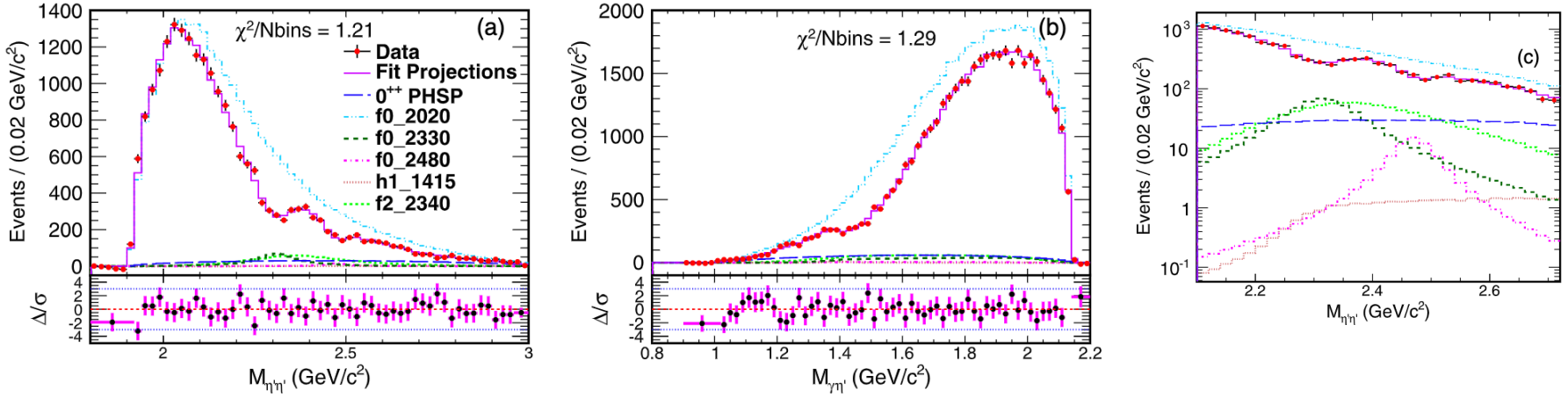
- Assuming $\eta_1(1855)$ is an additional resonance, scans of with different masses and widths
- Significant 1^{-+} contribution around **1.8 GeV/c²** needed





PWA of $J/\psi \to \gamma\eta'\eta'$

PRD105, 072002 (2022)



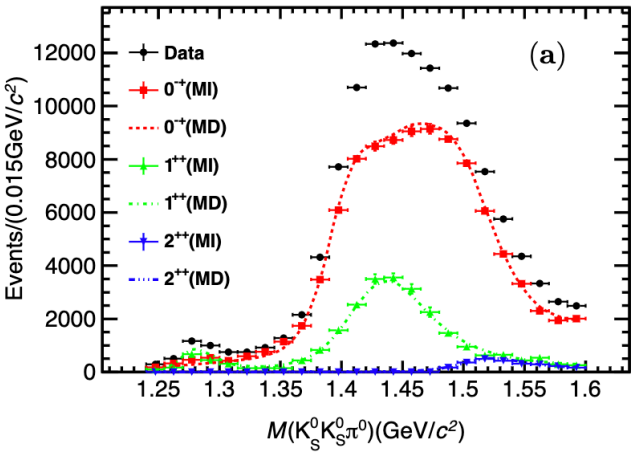
Resonance	M(MeV/c^2)	Γ(MeV)	B.F.	Significance (σ)
$f_0(2020)$	$1982 \pm 3^{+54}_{-0}$	$436 \pm 4^{+46}_{-49}$	$(2.63 \pm 0.06^{+0.31}_{-0.46}) \times 10^{-4}$	$\gg$25
$f_0(2330)$	$2312 \pm 2^{+10}_{-0}$	$134 \pm 5^{+30}_{-9}$	$(6.09 \pm 0.64^{+4.00}_{-1.68}) \times 10^{-6}$	16.3
$f_0(2480)$	$2470 \pm 4^{+4}_{-6}$	$75 \pm 9^{+11}_{-8}$	$(8.18 \pm 1.77^{+3.73}_{-2.23}) \times 10^{-7}$	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

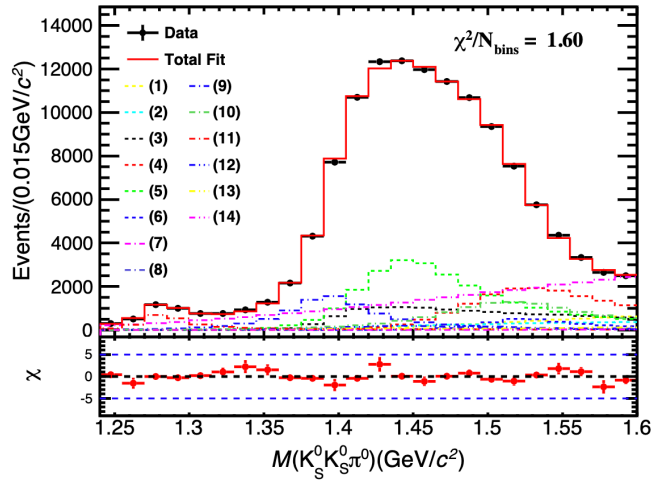
- new decay modes for $f_0(2020)$, $f_0(2330)$, and $f_0(2340)$
- new state $f_0(2480)$ firstly observed
- $f_0(2020)$ a scalar glueball? $\frac{\Gamma(f_0(2020) \to \eta\eta')}{\Gamma(f_0(2020) \to \eta'\eta')} = 0.0148$

PWA of $J/\psi \to \gamma K_S K_S \pi^0$

arXiv:2209.11175

- To explore the nature of $\eta(1405)$ and $\eta(1475)$: radial ex-citations of the η and η′? non-q$\bar{q}$ exotic state?
- A clean channel with negligible background





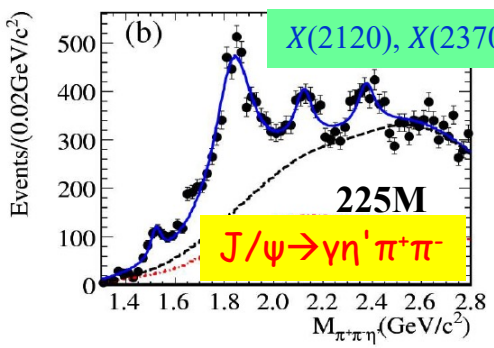
Components
(1). $J/\psi \to \gamma \mathrm{PHSP}(0^{-+}) \to \gamma K^*(892)^0 K_S^0 \to \gamma K_S^0 K_S^0 \pi^0$
(2). $J/\psi \to \gamma \mathrm{PHSP}(1^{++}) \to \gamma K^*(892)^0 K_S^0 \to \gamma K_S^0 K_S^0 \pi^0$
(3). $J/\psi \to \gamma \eta(1405) \to \gamma K_S^0 (K_S^0 \pi^0)_{\text{P-wave}} \to \gamma K_S^0 K_S^0 \pi^0$
(4). $J/\psi \to \gamma \eta(1475) \to \gamma K_S^0 (K_S^0 \pi^0)_{\text{P-wave}} \to \gamma K_S^0 K_S^0 \pi^0$
(5). $J/\psi \to \gamma f_1(1420) \to \gamma K^*(892)^0 K_S^0 \to \gamma K_S^0 K_S^0 \pi^0$
(6). $J/\psi \to \gamma f_2(1525) \to \gamma K^*(892)^0 K_S^0 \to \gamma K_S^0 K_S^0 \pi^0$
(7). $J/\psi \to \gamma \mathrm{PHSP}(0^{-+}) \to \gamma a_0(980)^0 \pi^0 \to \gamma K_S^0 K_S^0 \pi^0$
(8). $J/\psi \to \gamma \mathrm{PHSP}(2^{-+}) \to \gamma a_0(980)^0 \pi^0 \to \gamma K_S^0 K_S^0 \pi^0$
(9). $J/\psi \to \gamma \eta(1405) \to \gamma (K_S^0 K_S^0)_{\text{S-wave}} \pi^0 \to \gamma K_S^0 K_S^0 \pi^0$
(10). $J/\psi \to \gamma \eta(1475) \to \gamma (K_S^0 K_S^0)_{\text{S-wave}} \pi^0 \to \gamma K_S^0 K_S^0 \pi^0$
(11). $J/\psi \to \gamma f_1(1285) \to \gamma a_0(980)^0 \pi^0 \to \gamma K_S^0 K_S^0 \pi^0$
(12). $J/\psi \to \gamma f_1(1420) \to \gamma a_0(980)^0 \pi^0 \to \gamma K_S^0 K_S^0 \pi^0$
(13). $J/\psi \to \gamma \eta(1405) \to \gamma a_2(1320)^0 \pi^0 \to \gamma K_S^0 K_S^0 \pi^0$
(14). $J/\psi \to \gamma \eta(1475) \to \gamma a_2(1320)^0 \pi^0 \to \gamma K_S^0 K_S^0 \pi^0$

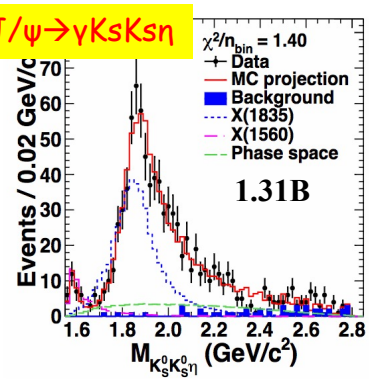
In MI-PWA, large flat 0^{-+} components between 1.4-1.5 GeV

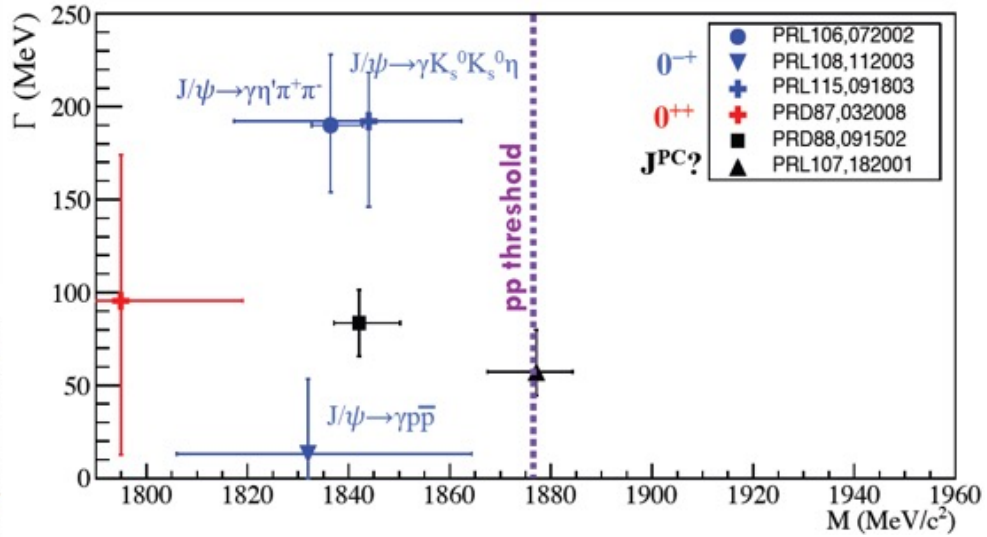
Resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV})$	Decay Mode	B.F.	Sig.(σ)
$\eta(1405)$	$1391.7 \pm 0.7^{+11.3}_{-0.3}$	$60.8 \pm 1.2^{+5.5}_{-12.0}$	$J/\psi \to \gamma\eta(1405) \to \gamma K_S^0 (K_S^0\pi^0)_{\text{P-wave}} \to \gamma K_S^0 K_S^0 \pi^0$	$(5.84 \pm 0.12^{+2.03}_{-3.36}) \times 10^{-5}$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

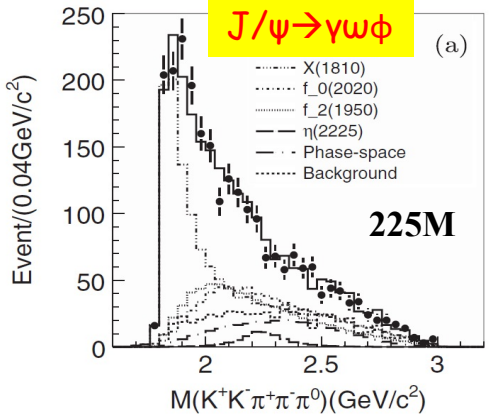
- Resonance parameters of the involved pseudoscalar, axial vector, and tensor states
- Data can be used for further investigations of the properties of the $\eta(1405)$ and $\eta(1475)$ mesons

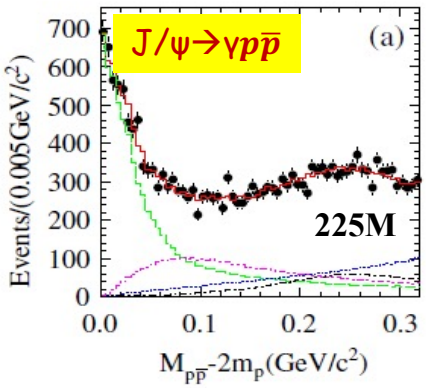
X($p\bar{p}$)/X(18??) from J/ψ radiative decays





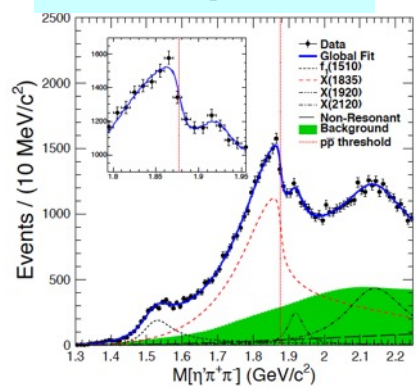






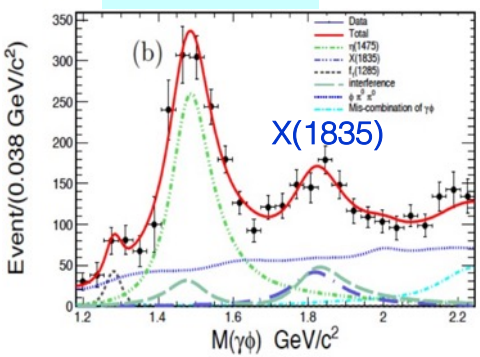
PRL117, 042002 (2016)

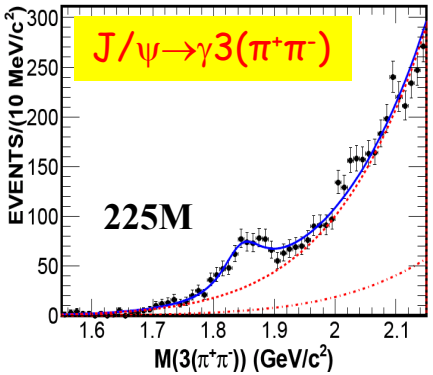
$J/\psi\to\gamma\eta'\pi^+\pi^-$

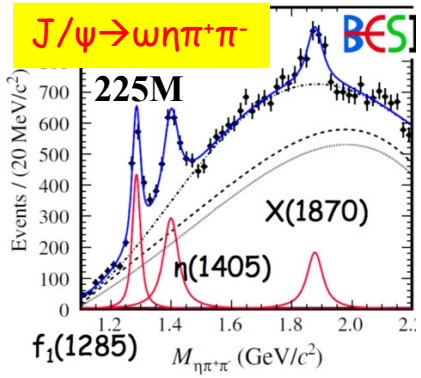


PRD97, 051101(R)(2018)

$J/\psi\to\gamma\gamma\phi$







Are they the same state? It is crucial to understand their connections.

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

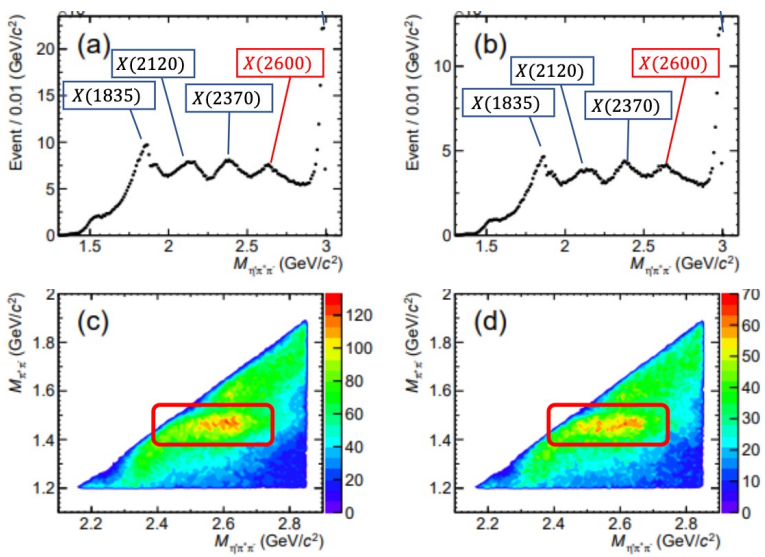
PRL129, 042001 (2022)

- 10B J/ψ events are analyzed, where $X(2120)$ and $X(2370)$ are confirmed
- A new state $\boldsymbol{X(2600)}$ 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 $\pi^+\pi^-$

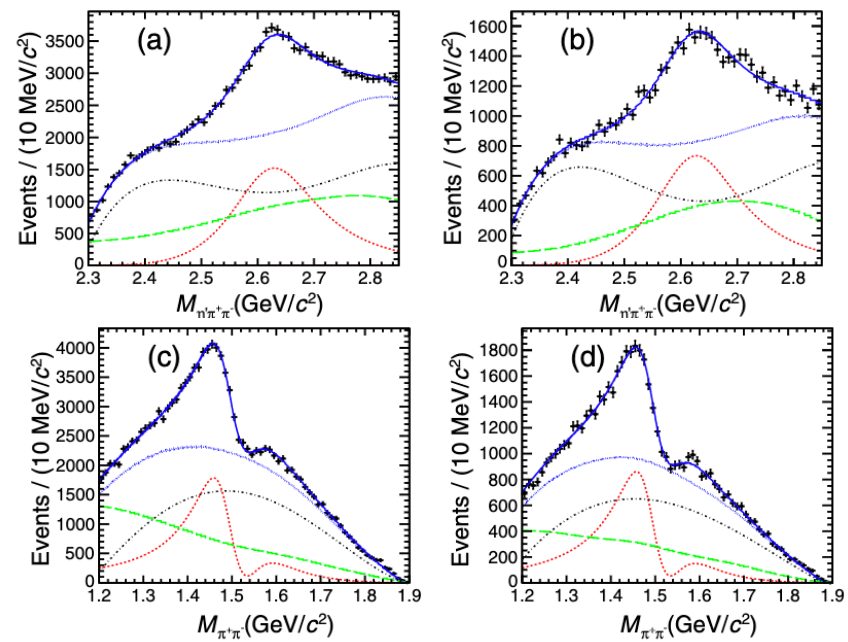
Resonance	Mass (MeV/c^2)	Width (MeV)
$f_0(1500)$	$1492.5 \pm 3.6^{+2.4}_{-20.5}$	$107 \pm 9^{+21}_{-7}$
$X(1540)$	$1540.2 \pm 7.0^{+36.3}_{-6.1}$	$157 \pm 19^{+11}_{-77}$
$X(2600)$	$2618.3 \pm 2.0^{+16.3}_{-1.4}$	$195 \pm 5^{+26}_{-17}$

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

Case	$f_0(1500)$	$X(1540)$
Events	24585 ± 1689	21203 ± 1456
BF ($\times 10^{-5}$)	$3.09 \pm 0.21^{+1.14}_{-0.77}$	$2.69 \pm 0.19^{+0.38}_{-1.21}$



reconstruct η' from $\gamma\pi^+\pi^-$(left) & $\eta(\to \gamma\gamma)\pi^+\pi^-$ (right)

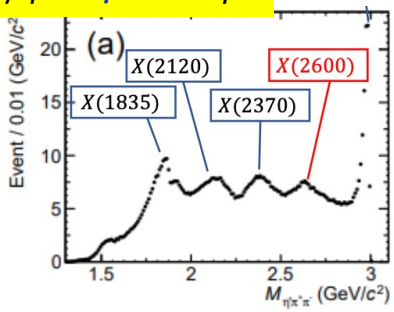


- $X(2600)$: 0^{-+} or 2^{-+} is favored. η radial excitation, or exotics?
- $X(1540)$: $f_2'(1525)$ or $f_2(1565)$?

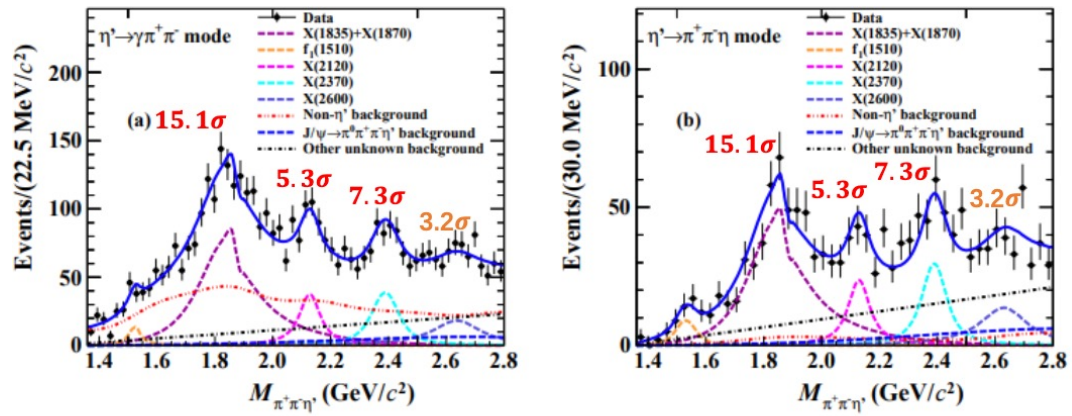
EM Dalitz decay of $J/\psi \to e^+e^-\pi^+\pi^-\eta'$

PRL129, 022002(2022)

$J/\psi \to \gamma\pi^+\pi^-\eta'$



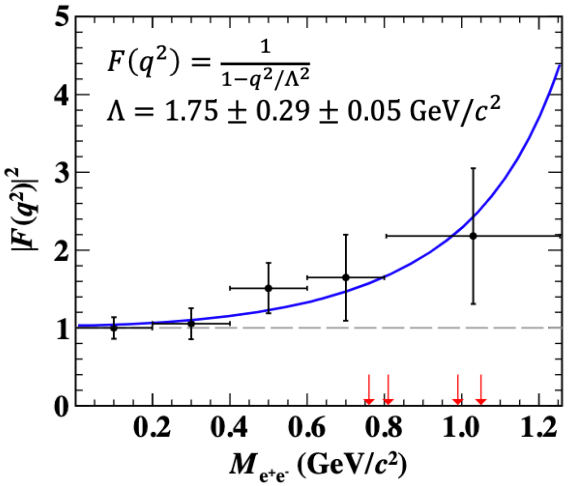
- Observation of X(1835), X(2120), and X(2370) in EM Dalitz decays
- First measurement of the TFF between J/ψ and X(1835)



reconstruct η' from $\gamma\pi^+\pi^-$(left) & $\eta(\to\gamma\gamma)\pi^+\pi^-$ (right)

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)	$(4.43 \pm 0.23 \pm 0.19) \times 10^{-6}$
$X = X(2120)$		$(0.82 \pm 0.12 \pm 0.06) \times 10^{-6}$
$X = X(2370)$		$(1.08 \pm 0.14 \pm 0.10) \times 10^{-6}$

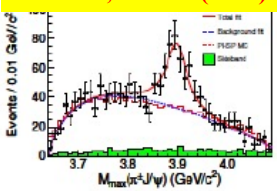
$$\frac{d\Gamma(J/\psi \to X(1835)e^+e^-)}{dq^2\Gamma(J/\psi \to X(1835)\gamma)} = |F(q^2)|^2 \times [\mathrm{QED}(q^2)],$$



The Zc and Zcs Family at BESIII

Zc(3900)$^+$

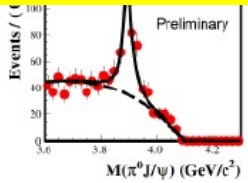
PRL 110, 252001 (2013)



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

Zc(3900)^0

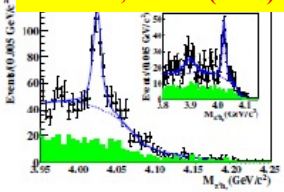
PRL 115, 112003 (2015)



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

Zc(4020)$^+$

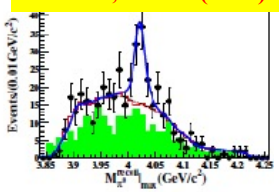
PRL 111, 242001(2013)



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

Zc(4020)^0

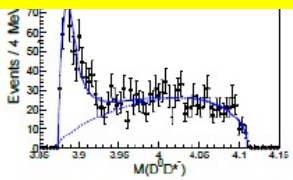
PRL113,212002 (2014)



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

Zc(3885)$^+$

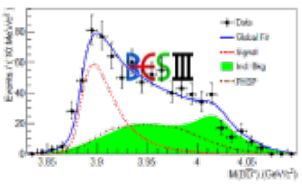
ST: PRL 112, 022001(2014)
DT: PRD92, 092006 (2015)



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

Zc(3885)^0

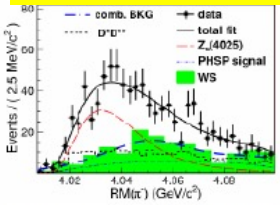
PRL 115, 222002 (2015)



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

Zc(4025)$^+$

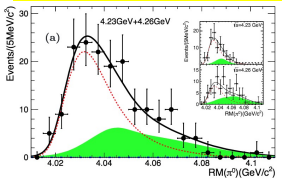
PRL 112, 132001 (2014)



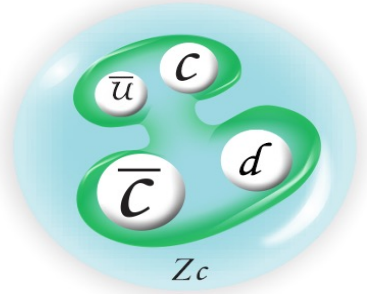
$e^+e^- \to \pi^-(D^*\bar{D}^*)^+$

Zc(4025)^0

PRL115, 182002 (2015)

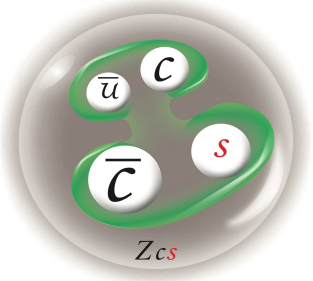


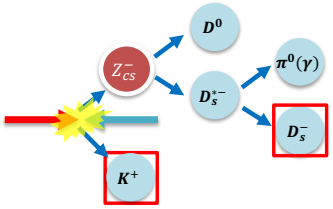
$e^+e^- \to \pi^0(D^*\bar{D}^*)^0$



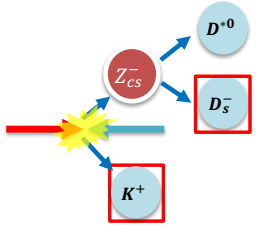
SU(3) counter-part

Zcs state with strangeness



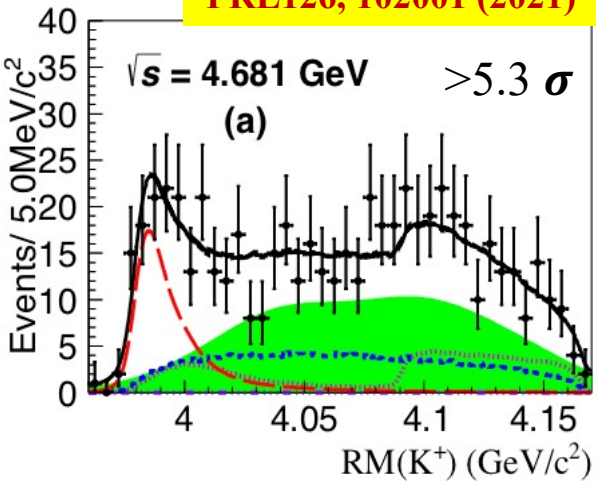


$e^+e^- \to K^+ D_s^{*-} D^0$



$e^+e^- \to K^+ D_s^- D^{*0}$

PRL126, 102001 (2021)



Observation of the $Z_{cs}(3985)^{\pm}$

$$m = 3985.2^{+2.1}_{-2.0} \pm 1.7\ \mathrm{MeV/c^2}$$
$$\Gamma = 13.8^{+8.1}_{-5.2} \pm 4.9\ \mathrm{MeV}$$

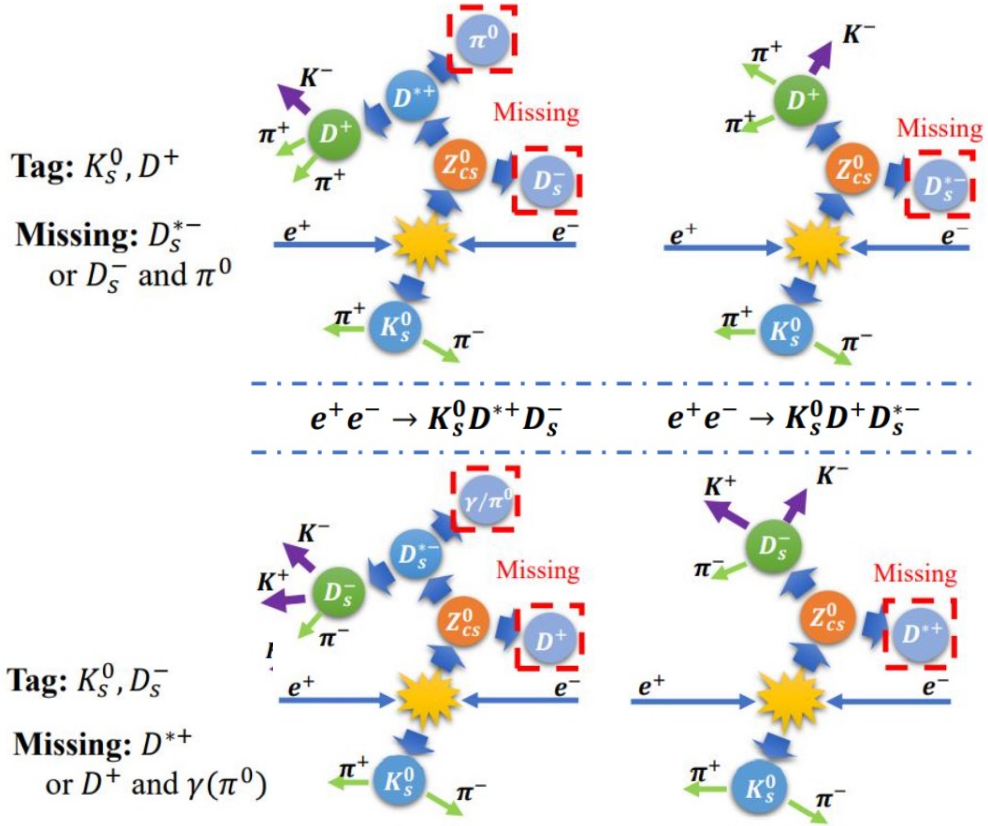
First candidate of the hidden-charm tetraquark with strangeness!

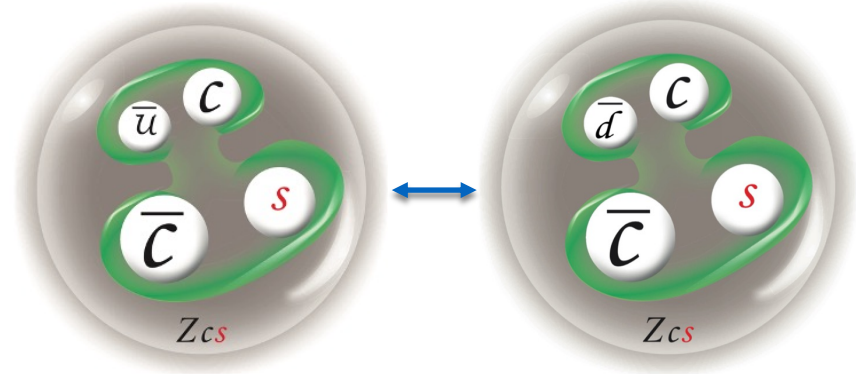
Evidence for the neutral $Z_{cs}(3985)^0$

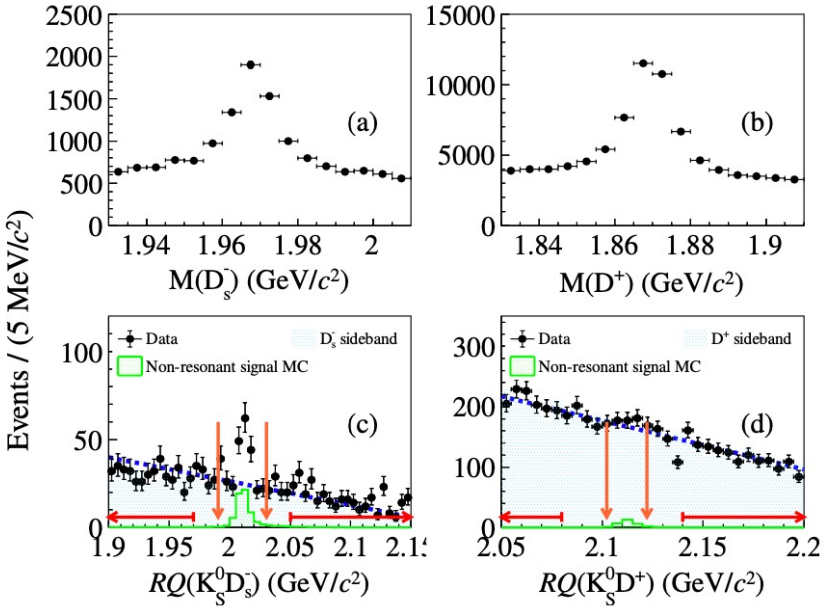
PRL 129, 112003 (2022)

3.7fb^{-1} data accumulated at 4.628-4.698 GeV

Partial reconstruction

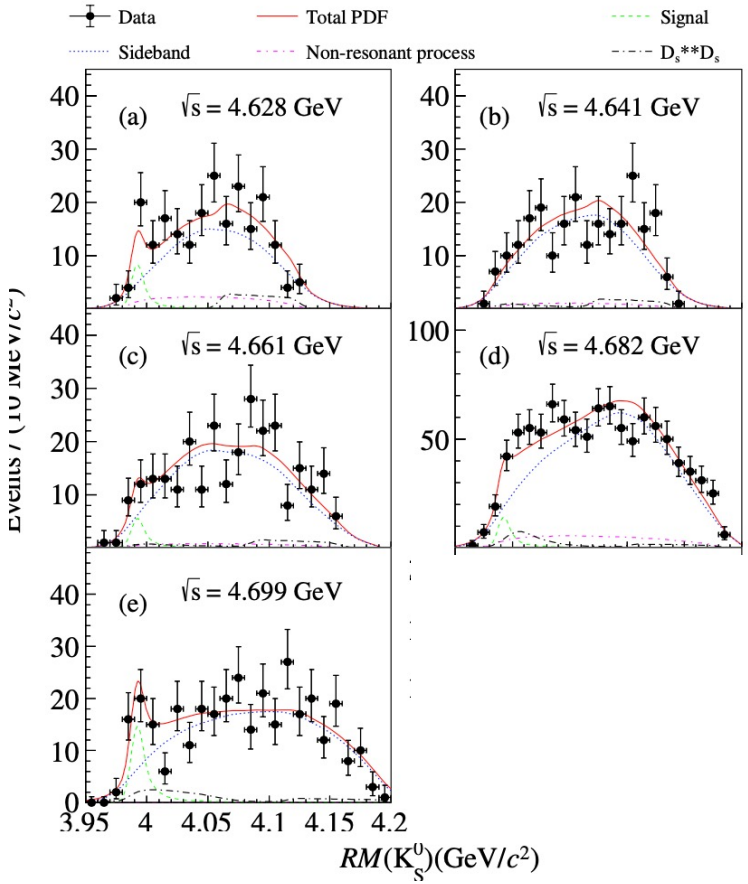




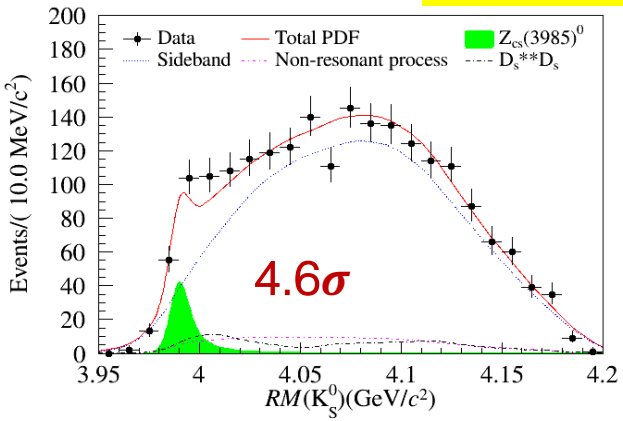


- The D_s^+ and D^+ are reconstructed through
  - $D_s^- \to K^+K^-\pi^-$, $K^+K^-\pi^-\pi^0$, $K_s^0K^-$, $K_s^0K^+\pi^-\pi^-$, $\eta'\pi^-$
  - $D^+ \to K^-\pi^+\pi^+$, $K_s^0\pi^+$, $K_s^0\pi^+\pi^+\pi^-$

Evidence for the neutral $Z_{cs}(3985)^0$



PRL 129, 112003 (2022)



$\sqrt{s}$ (MeV)	$\sigma^{\rm Born} \times \mathcal{B}$ (pb) $\bar{K}^0 Z_{cs}(3985)^0$	$K^- Z_{cs}(3985)^+$	χ^2	$\chi^2_{\rm total}$/ndf
4628	$4.4^{+2.6}_{-2.2} \pm 2.0$	$0.8^{+1.2}_{-0.8} \pm 0.6$	1.2	
4641	$0.0^{+1.6}_{-0.0} \pm 0.2$	$1.6^{+1.2}_{-1.1} \pm 1.3$	0.5	
4661	$2.8^{+1.8}_{-1.6} \pm 0.6$	$1.6^{+1.3}_{-1.1} \pm 0.8$	0.3	5.1/5
4682	$2.2^{+1.2}_{-1.0} \pm 0.8$	$4.4^{+0.9}_{-0.8} \pm 1.4$	1.0	
4699	$7.0^{+2.2}_{-2.0} \pm 1.8$	$2.4^{+1.1}_{-1.0} \pm 1.2$	2.1	

	Mass (MeV/c^2)	Width (MeV)
$Z_{cs}(3985)^0$	$3992.2 \pm 1.7 \pm 1.6$	$7.7^{+4.1}_{-3.8} \pm 4.3$
$Z_{cs}(3985)^+$	$3985.2^{+2.1}_{-2.0} \pm 1.7$	$13.8^{+8.1}_{-5.2} \pm 4.9$

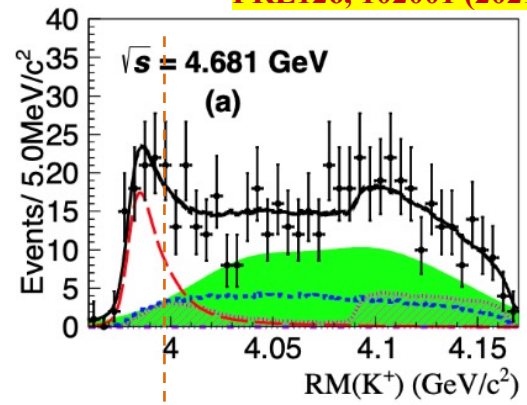
- Mass and width consistent with the charged Zcs: $m(Zcs^+)<m(Zcs^0)$
- Cross sections are consistent under isospin symmetry

➔ they are isospin partners

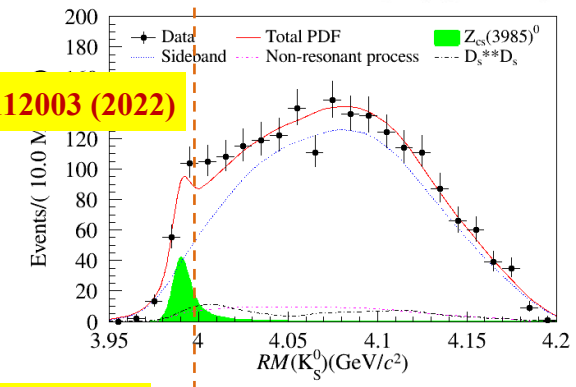
Discussions on the nature of $Z_{cs}(3985)$

- Various interpretations are possible for the structure
  - Tetraquark state
  - Molecule
  - $D_{s2}^{*}(2573)^{+}D_{s}^{*-}$ threshold kinematic effects (Re-scattering , Reflection, Triangle singularity)
  - Mixture of molecular and tetraquark
  - …

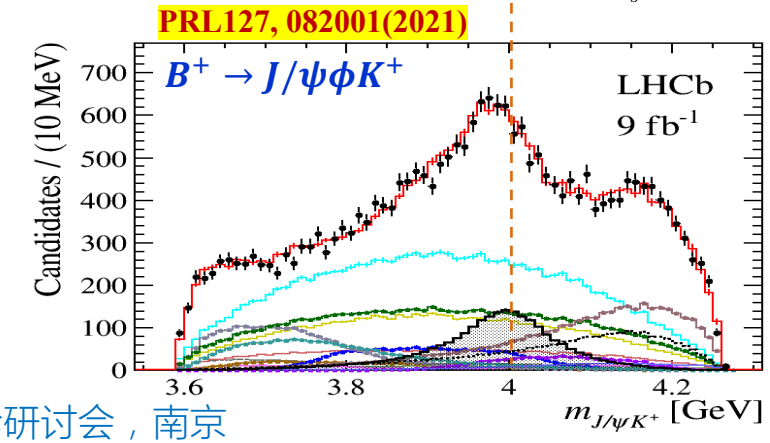
PRL126, 102001 (2021)



PRL 129, 112003 (2022)



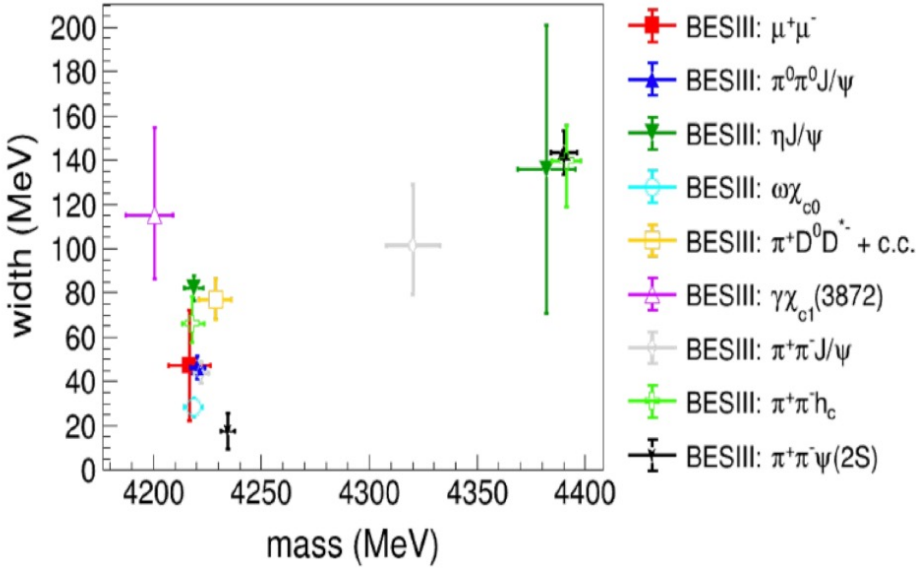
PRL127, 082001(2021)

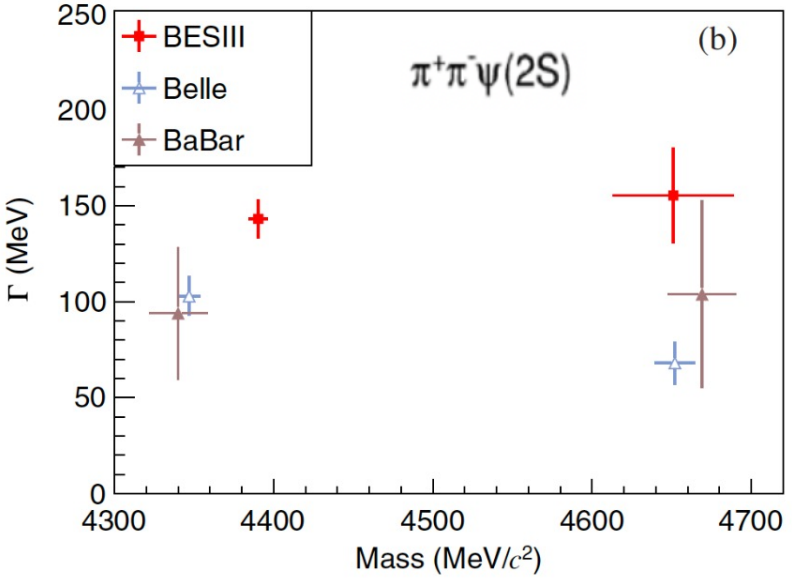


$Z_{cs}(3985)$ from e^+e^- annihilations and $Z_{cs}(4000)$ from B decays

- their masses are close, but widths are different
- If they are same, why width so different?
- If they are not same, is there the corresponding wide Zc(3900)?
- Looking for more channels will be useful

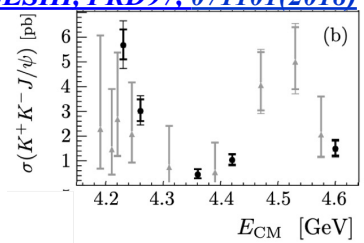
Y(4230), Y(43XX) and Y(4660)



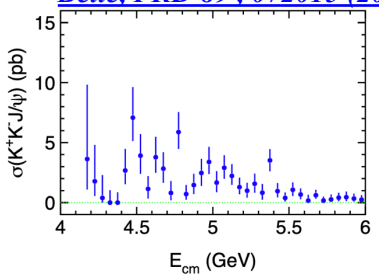


Cross sections of $e^+e^- \to K^+K^-J/\psi$

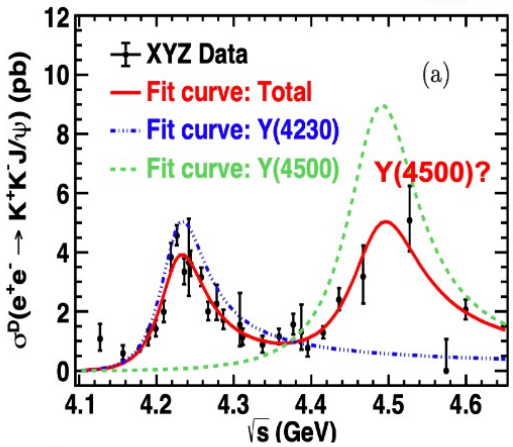
BESIII, PRD97, 071101(2018)

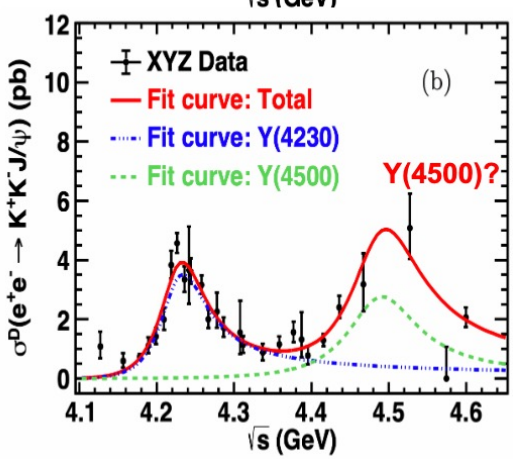


Belle, PRD 89 , 072015 (2014)



arXiv:2204.07800





Investigating the strange content inside Y(4230)

- ✓ First observation of Y(4230) → K^+K^-J/ψ peak

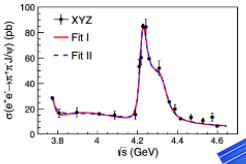
$$0.02 < \frac{\mathcal{B}(Y(4230) \to K^+K^-J/\psi)}{\mathcal{B}(Y(4230) \to \pi^+\pi^-J/\psi)} < 0.26$$

- ✓ Resonance Y(4500) > 5σ, consistent with the predictions of:
  - 5S-4D mixing scheme (PRD99,114003 (2019))
  - heavy-antiheavy hadronic molecules model (ProgrPhys41,65(2021))
  - Lattice QCD result for a $(cs\bar{c}\bar{s})$ state (PRD73,094510 (2006))

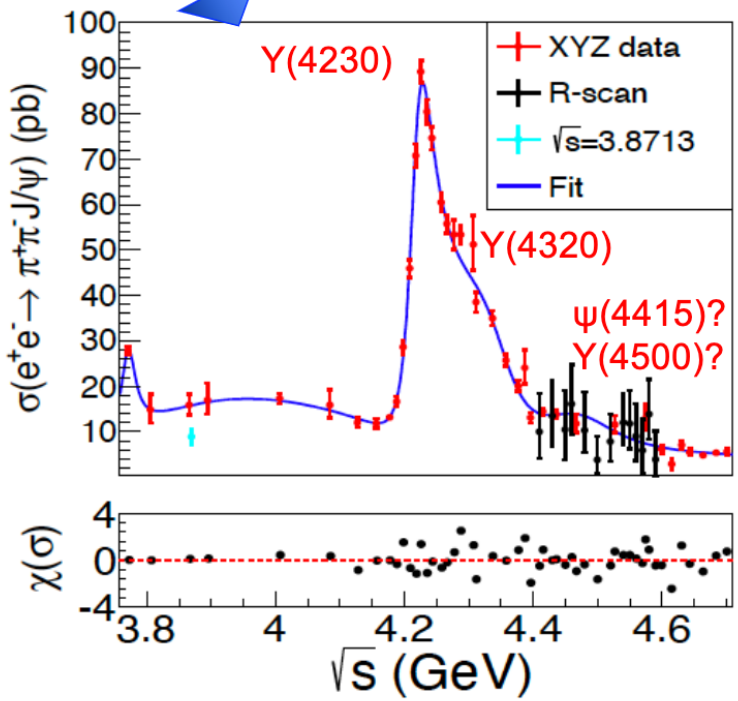
	Parameters	Solution I	Solution II
$Y(4230)$	M(MeV)	$4225.3 \pm 2.3 \pm 21.5$	
	Γ_{tot}(MeV)	$72.9 \pm 6.1 \pm 30.8$	
	$\Gamma_{ee}\mathcal{B}$(eV)	$0.42 \pm 0.04 \pm 0.15$	$0.29 \pm 0.02 \pm 0.10$
$Y(4500)$	M(MeV)	$4484.7 \pm 13.3 \pm 24.1$	
	Γ_{tot}(MeV)	$111.1 \pm 30.1 \pm 15.2$	
	$\Gamma_{ee}\mathcal{B}$(eV)	$1.35 \pm 0.14 \pm 0.06$	$0.41 \pm 0.08 \pm 0.13$
phase angle	φ(rad)	$1.72 \pm 0.09 \pm 0.52$	$5.49 \pm 0.35 \pm 0.58$

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

arXiv:2206.08554



Higher statistics, higher precision, higher energies, better fit



- ✓ Y(4230) and Y(4320) observed with > 10σ
- ✓ Structure around 4 GeV better fit by a BW (before exp)
- ✓ Evidence ~3σ of a structure at higher energies
  ψ(4415)? The new Y(4500)?
- ✓ By including the high energy state in the fit, the Y(4320) parameters change

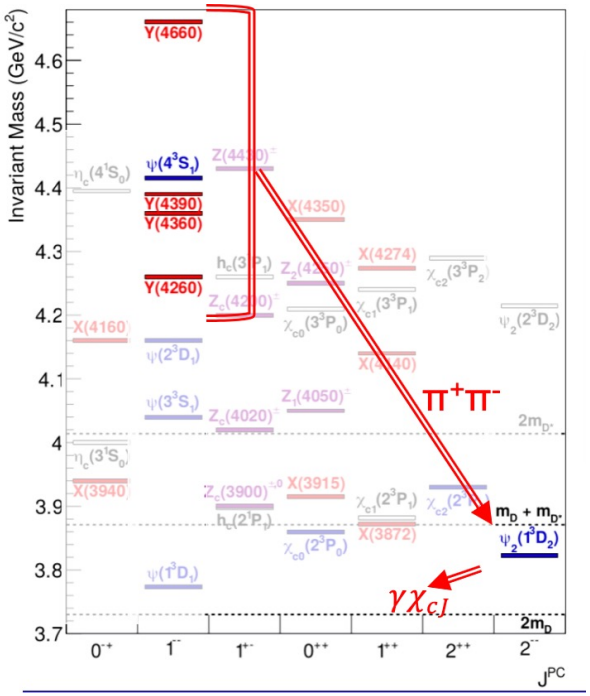
$M_{Y(4230)} = 4221.4 \pm 1.5 \pm 2.0$ MeV/c^2
$\Gamma_{Y(4230)} = 41.8 \pm 2.9 \pm 2.7$ MeV

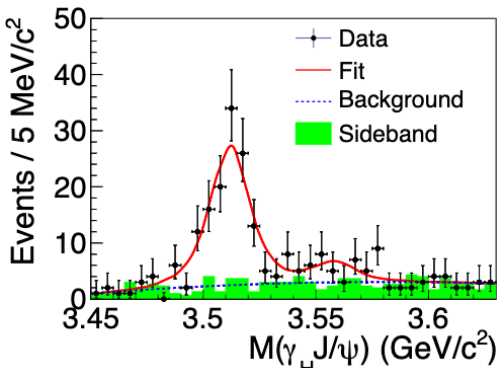
$M_{Y(4320)} = 4298 \pm 12 \pm 26$ MeV/c^2
$\Gamma_{Y(4320)} = 127 \pm 17 \pm 10$ MeV

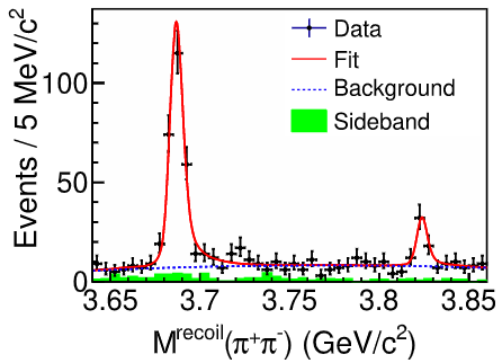
Cross sections of $e^+e^- \to \pi^+\pi^-\psi(3823)$

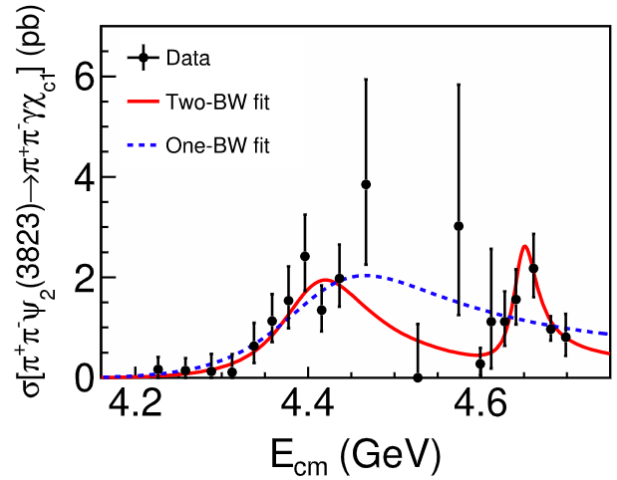
PRL129, 102003 (2022)

first observation of vector Y states decaying to D-wave charmonium state









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

Most precise measurement

mass and width of $\psi_2(3823)$:
$m = 3823.12 \pm 0.43 \pm 0.13\ \mathrm{MeV}/c^2$
$\Gamma < 2.9$ MeV (at 90% CL)

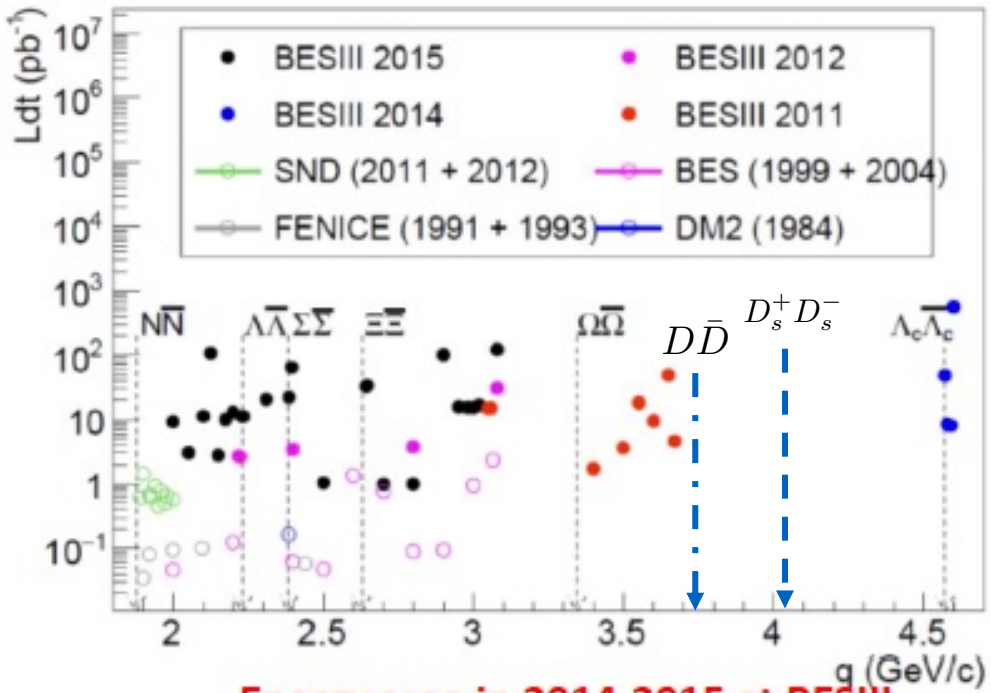
$$\frac{\mathcal{B}[\psi_2(3823)\to\gamma\chi_{c2}]}{\mathcal{B}[\psi_2(3823)\to\gamma\chi_{c1}]} = 0.33 \pm 0.12 (< 0.51))$$

- R_1 and R_2 consistent with Y(4360) and Y(4660)
- BESIII also observes $e^+e^- \to \pi^0\pi^0\psi(3823)$ [arXiv:2209.14744], consistent with isospin symmetry

Unique data sets near thresholds

e^+e^- symmetric collision: energy scan data sets at open charm thresholds

3.773 GeV, ~8 fb^{-1}, $D\bar{D}$
4.008 GeV, 0.48 fb^{-1}, $D_s\bar{D}_s$
4.18-4.23 GeV, 6.32 fb^{-1}, $D_s\bar{D}_s^*$
4.6-4.95 GeV, 6.4 fb^{-1}, $\Lambda_c\bar{\Lambda}_c$



Energy scan in 2014-2015 at BESIII

- **Meson and Baryon pair-productions near thresholds: form-factors in the time-like production, precision branching fractions, relative phase;**
- **Quantum-entangled pair productions of charmed mesons**
- **Hyperon and charmed baryon spin polarization in quantum entangled productions;**

BESIII advantage: unique data near to the thresholds

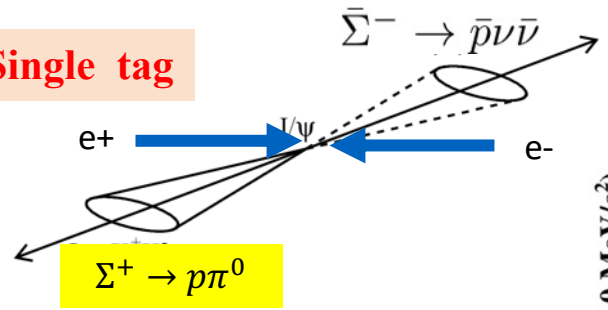
Known initial 4-momentum

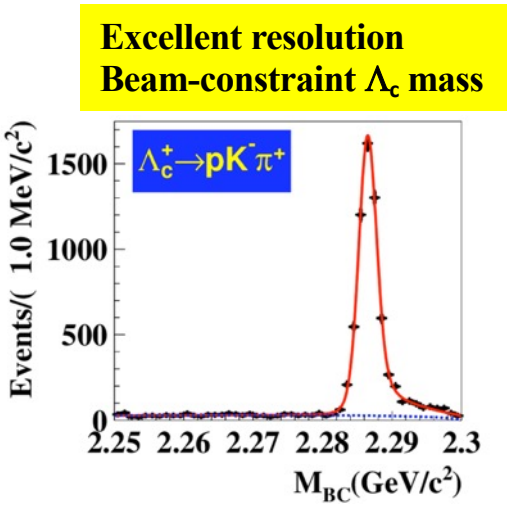
Known beam energy: pair productions

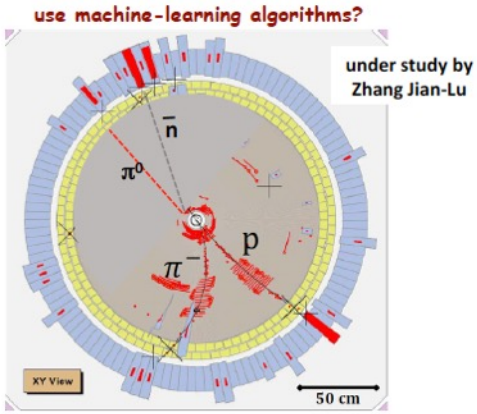
Decay with neutron & π^0

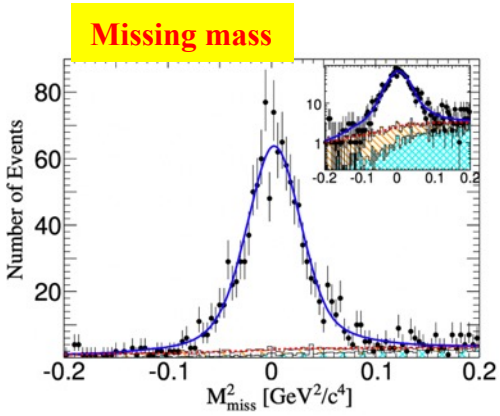
Decay with invisibles: neutrinos

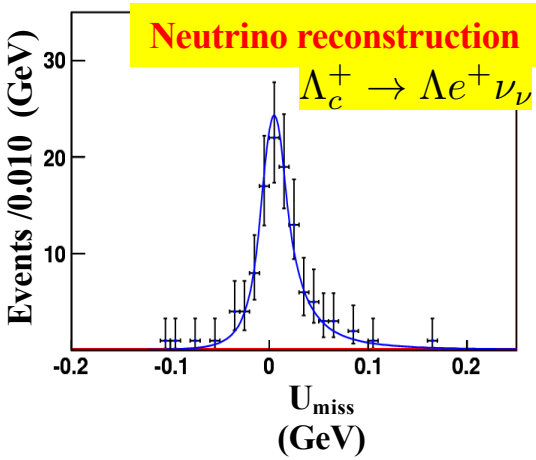
Missing mass or missing energy

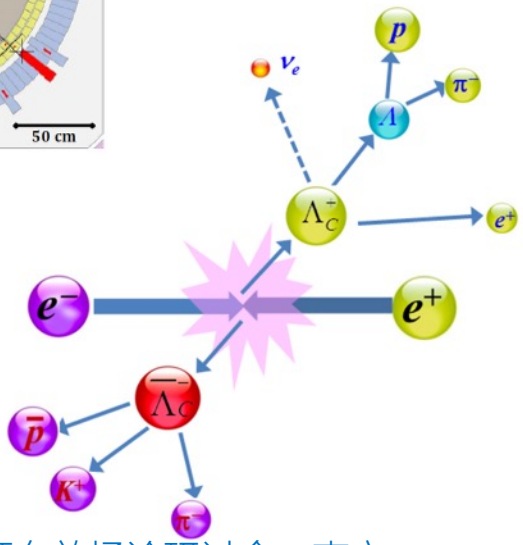




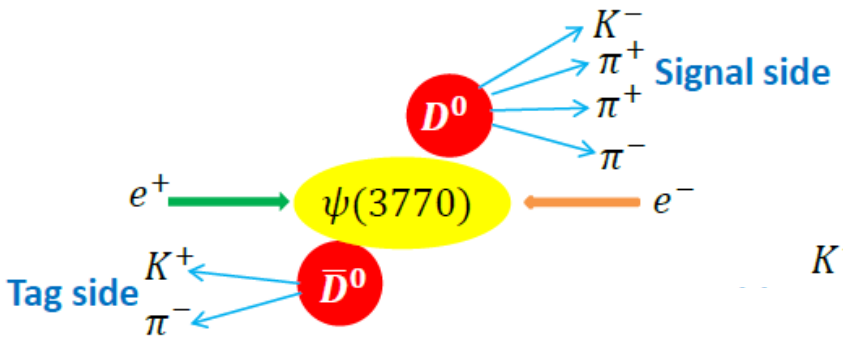




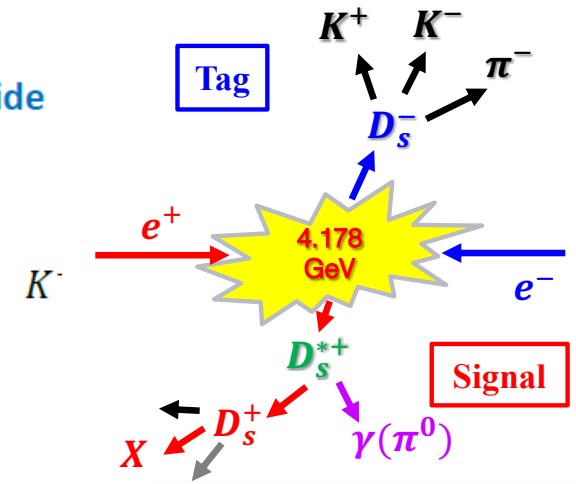


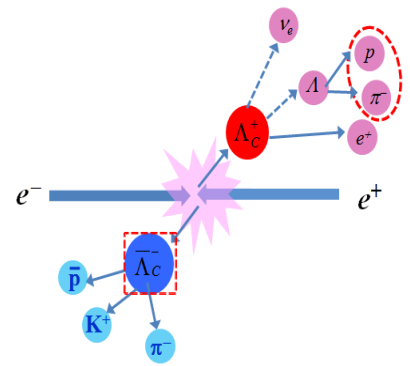


Charm hadron decays

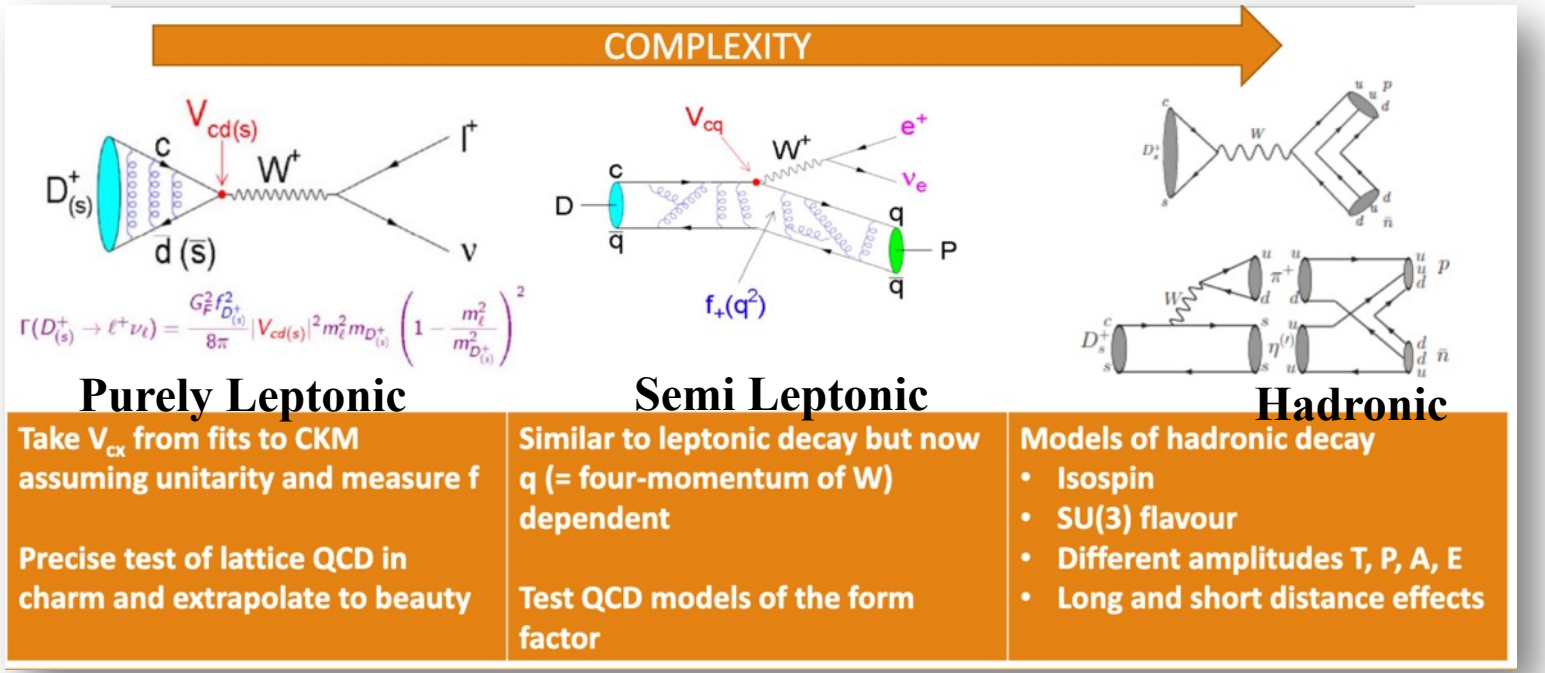


2.93/fb at $\psi(3770)$





0.567/fb at 4.6 GeV

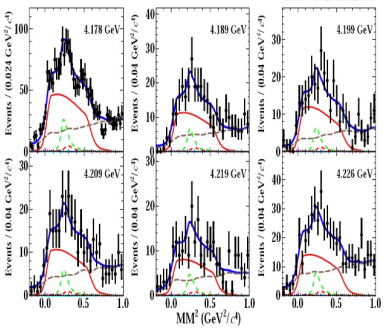


f_{D^+} and $f_{D_s^+}$

PRD104(2021)032001

$D_s^+ \to \tau^+(\rho^+\nu)\nu$

6.3 fb^{-1} 1745±84

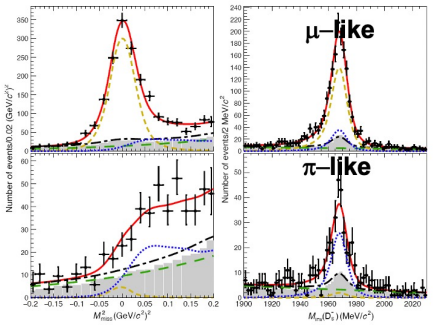


$f_{D_s^+}|V_{cs}| = (244.8 \pm 5.8 \pm 4.8)$ MeV

PRD104(2021)052009

$D_s^+ \to \tau^+(\pi^+\nu)\nu$

6.3 fb^{-1} 946±46

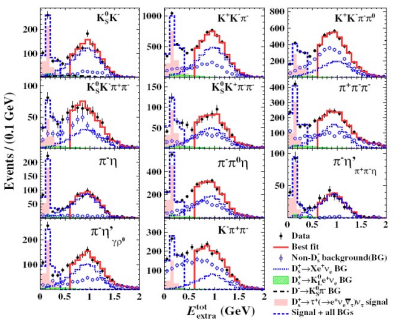


$f_{D_s^+}|V_{cs}| = (243.0 \pm 5.8 \pm 4.0)$ MeV

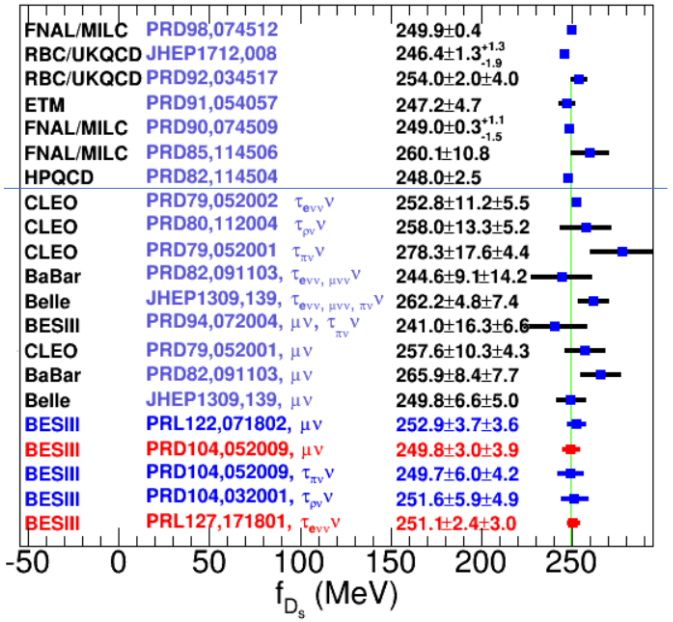
PRL127(2021)171801

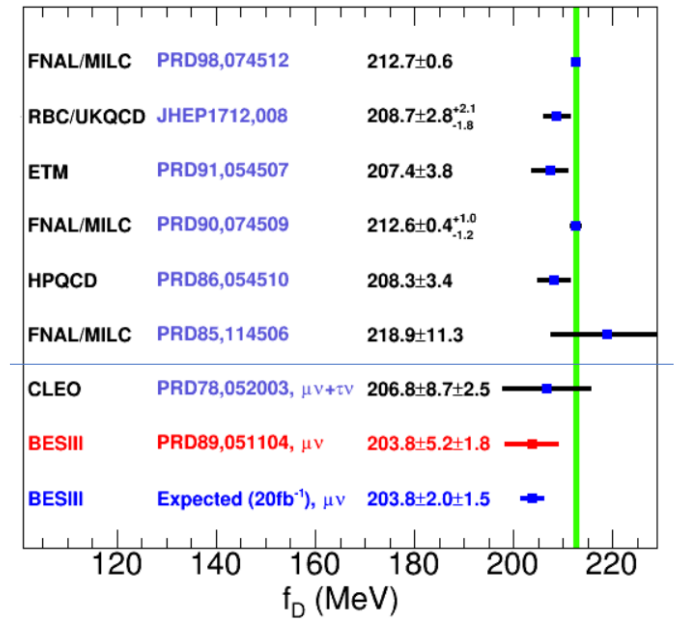
$D_s^+ \to \tau^+(e^+\nu\nu)\nu$

6.3 fb^{-1} 4940±97

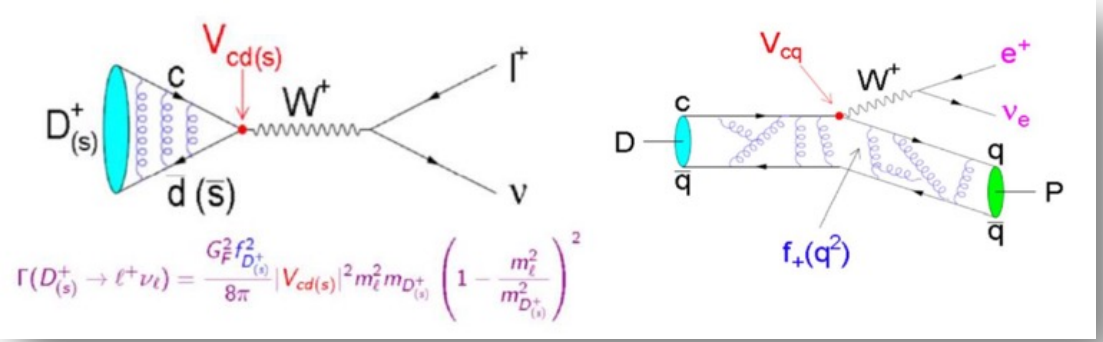


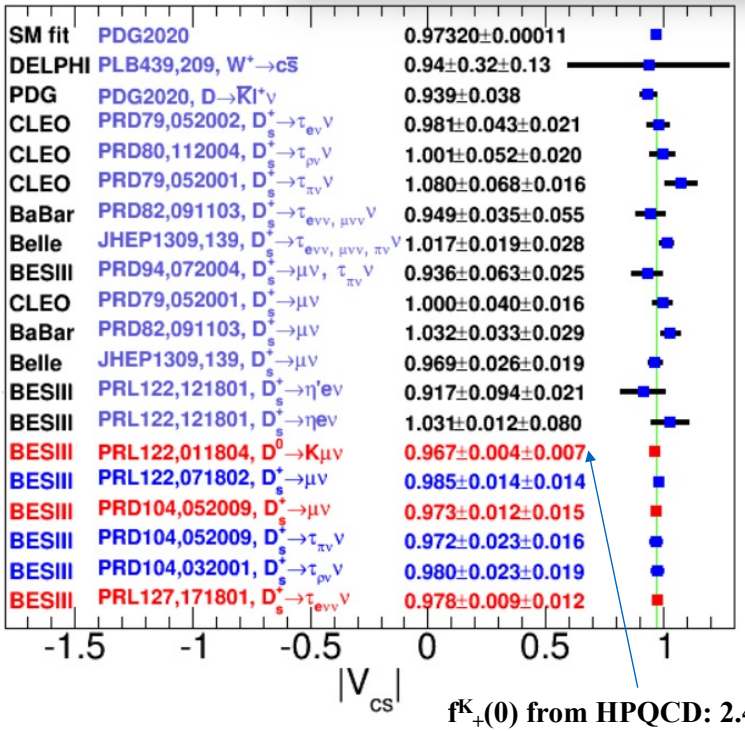
$f_{D_s^+}|V_{cs}| = (244.4 \pm 2.3 \pm 2.9)$ MeV

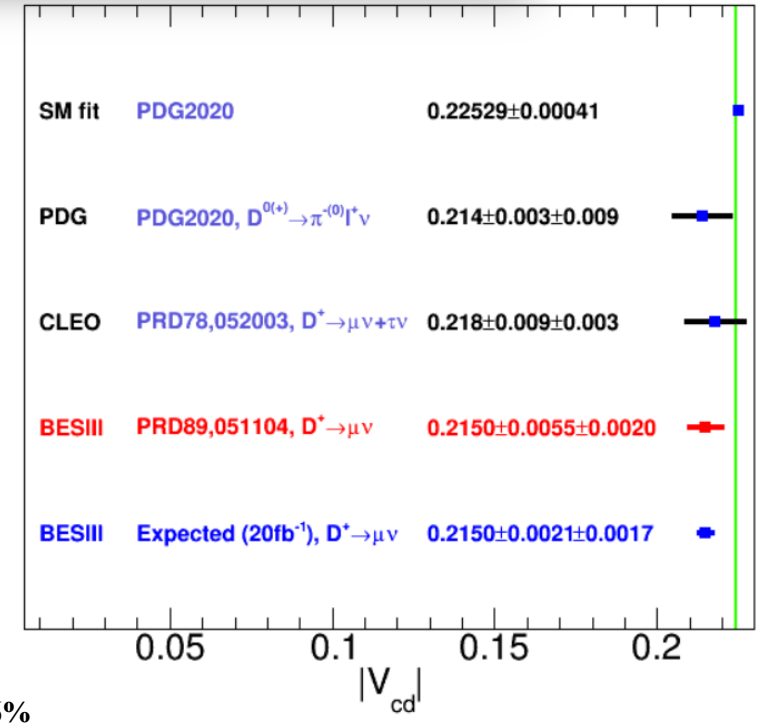




Most precise direct measurement of |Vcs| and |Vcd|





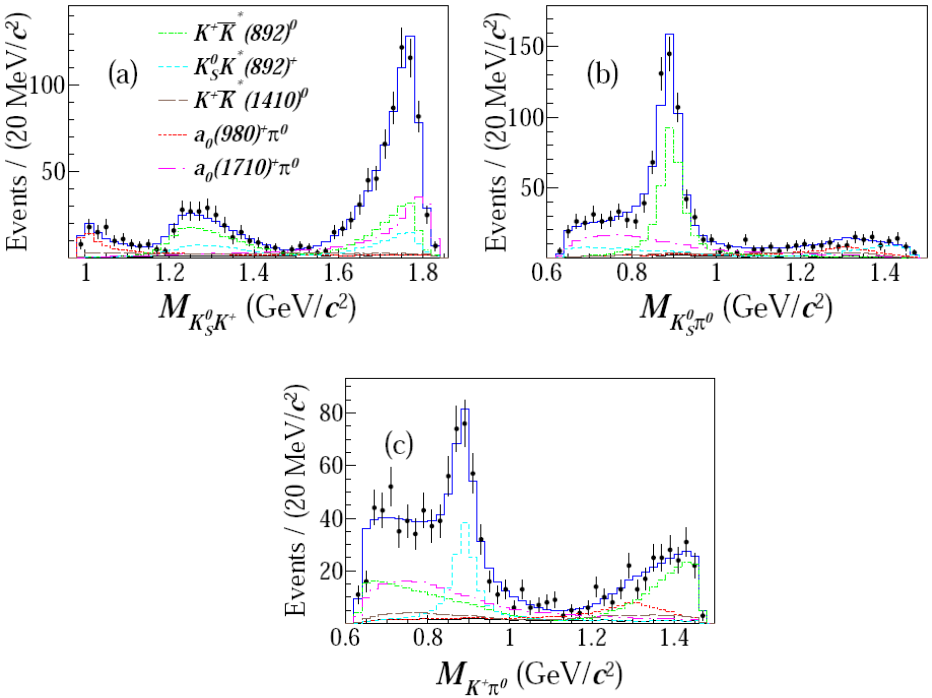


$f^K_+(0)$ from HPQCD: 2.4%→0.6%

D hadronic decays

Amplitude analysis of $D_s^+ \to K_S K^+ \pi^0$

arXiv:2204.09614



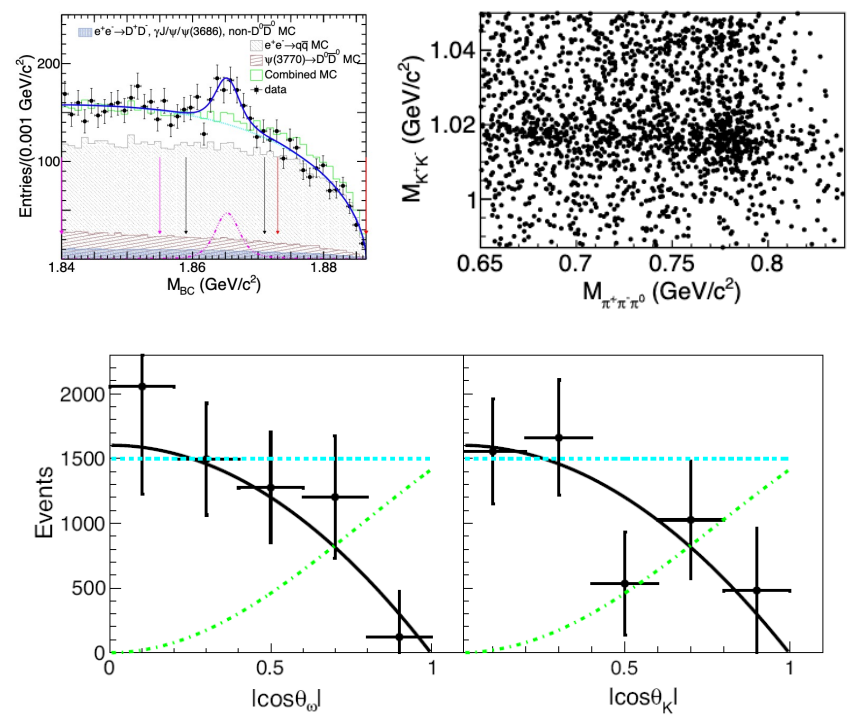
Observation of $a_0(1710)^+$, the isovector partner of the $f_0(1710)$ and $f_0(1770)$

$$M = (1.817 \pm 0.008 \pm 0.020)\mathrm{GeV}/c^2$$

$$\Gamma = (97 \pm 22 \pm 15)\mathrm{MeV}$$

Observation of $D^+ \to \omega\phi$

PRL128, 011803(2022)



Angular distribution studies reveal that the ω and ϕ in the D^0 decay are transversely polarized, which contradicts predictions from the naive factorization and Lorentz invariant-based symmetry models.

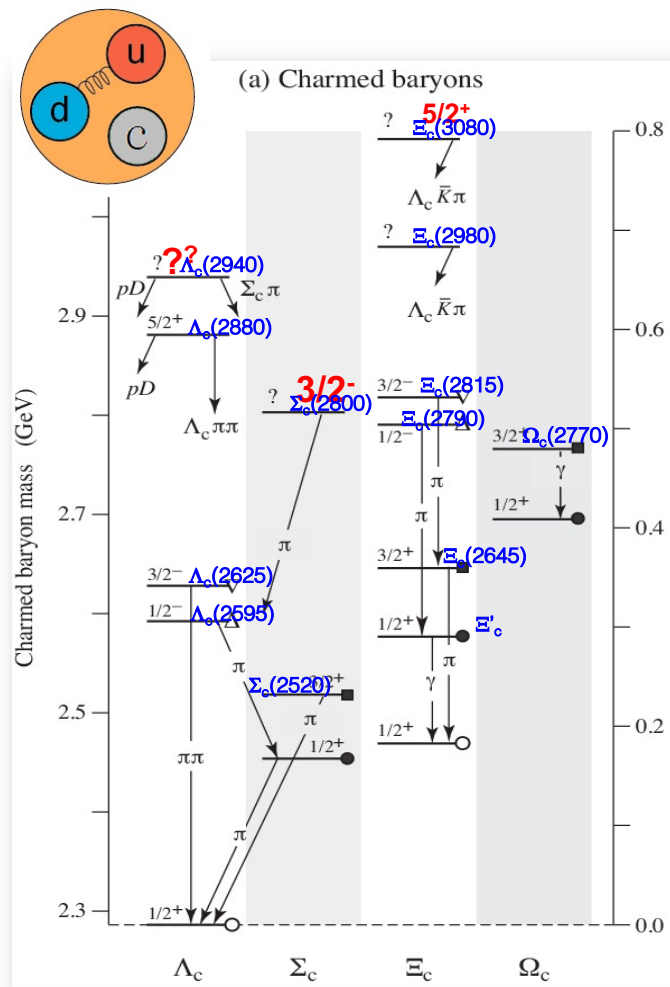
New Λ_c data is available!

2014：0.567 fb^{-1} at 4.6 GeV

Hadronic decay	
$\Lambda_c^+ \to pK^-\pi^+$ + 11 CF modes	PRL 116, 052001 (2016)
$\Lambda_c^+ \to pK^+K^-$, $p\pi^+\pi^-$	PRL 117, 232002 (2016)
$\Lambda_c^+ \to nK_s\pi^+$	PRL 118, 12001 (2017)
$\Lambda_c^+ \to p\eta$, $p\pi^0$	PRD 95, 111102(R) (2017)
$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$	PLB 772, 388 (2017)
$\Lambda_c^+ \to \Xi^{0(*)}K^+$	PLB783, 200 (2018)
$\Lambda_c^+ \to \Lambda\eta\pi^+$	PRD99, 032010 (2019)
$\Lambda_c^+ \to \Sigma^+\eta, \Sigma^+\eta'$	CPC43, 083002 (2019)
$\Lambda_c^+ \to$ BP decay asymmetries	PRD100, 072004 (2019)
$\Lambda_c^+ \to pK_s\eta$	PLB 817, 136327 (2021)
Λ_c^+ spin determination	PRD 103, L091101(2021)
Semi-leptonic decay	
$\Lambda_c^+ \to \Lambda e^+\nu_e$	PRL 115, 221805(2015)
$\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$	PLB 767, 42 (2017)
Inclusive decay	
$\Lambda_c^+ \to \Lambda X$	PRL121, 062003 (2018)
$\Lambda_c^+ \to e^+X$	PRL 121 251801(2018)
$\Lambda_c^+ \to K_S^0X$	EPJC 80, 935 (2020)
Production	
$\Lambda_c^+\Lambda_c^-$ cross section	PRL 120,132001(2018)

Very productive for the data taken in 35 days!

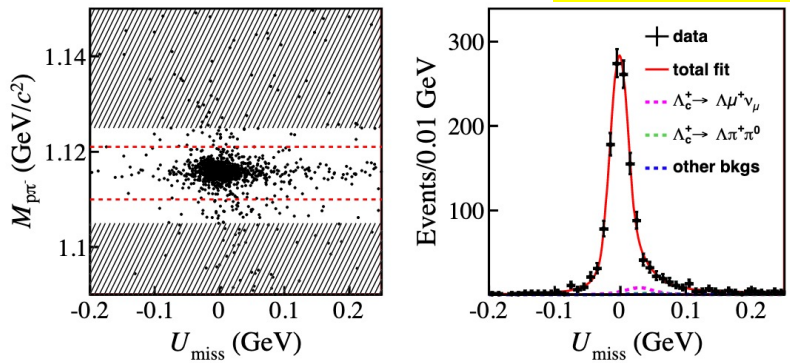
~8 times more Λ_c samples are accumulated in 2020 and 2021



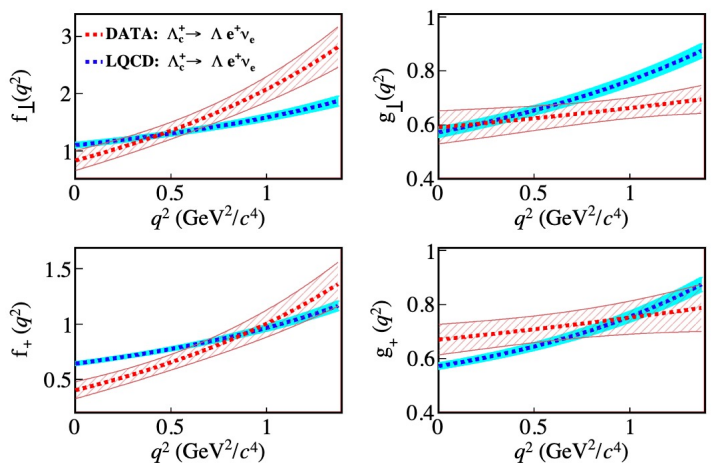
Recent results on Λ_c^+ leptonic decays

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

arXiv:2207.14149



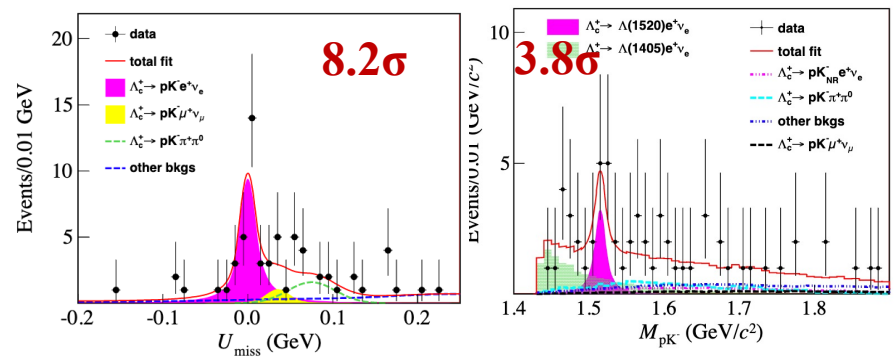
$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$



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

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

arXiv: 2207.11483



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

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

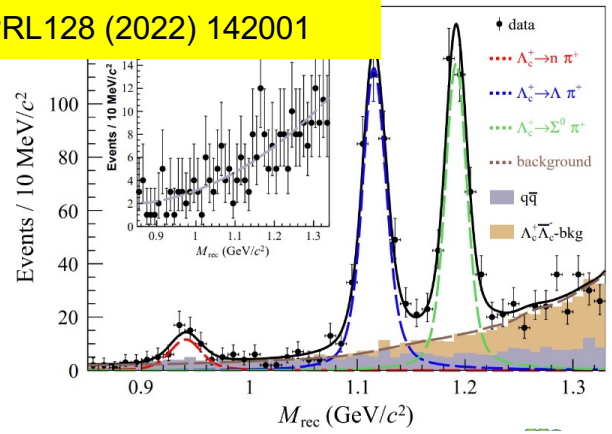
$B(\Lambda_c^+ \to \Lambda(1520) e^+ \nu) =$
$(0.99 \pm 0.51 \pm 0.10) \times 10^{-3}$

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

Recent results on Λ_c hadronic decays

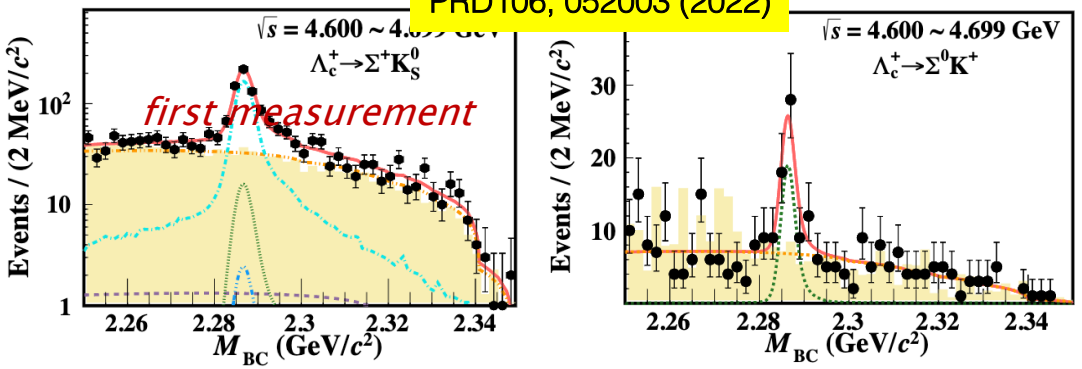
Observation of $\Lambda_c^+ \to n\pi^+$

PRL128 (2022) 142001



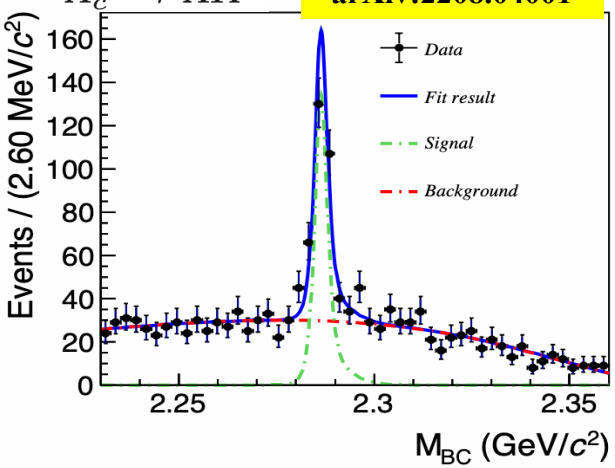
Determination of the BF for $\Lambda_c^+ \to \Sigma^+ K_S$ and $\Sigma^0 K^+$

PRD106, 052003 (2022)



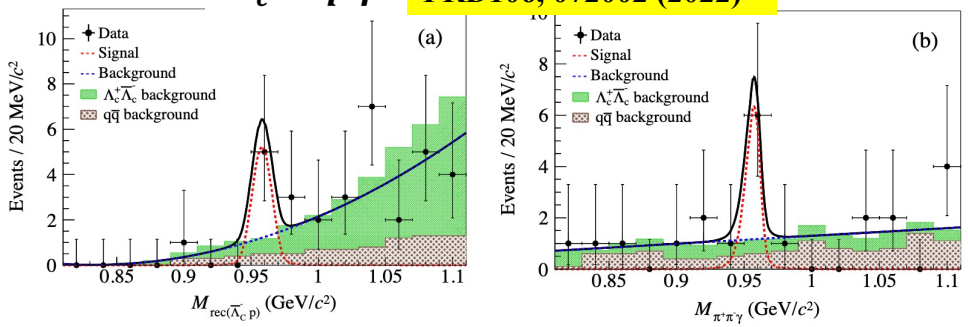
$\Lambda_c^+ \to \Lambda K^+$

arXiv:2208.04001

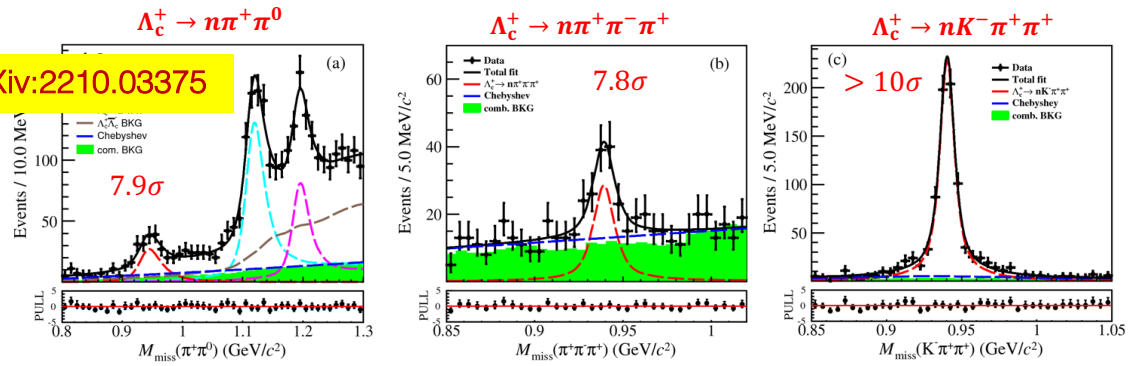


$\Lambda_c^+ \to p\eta'$

PRD106, 072002 (2022)



arXiv:2210.03375

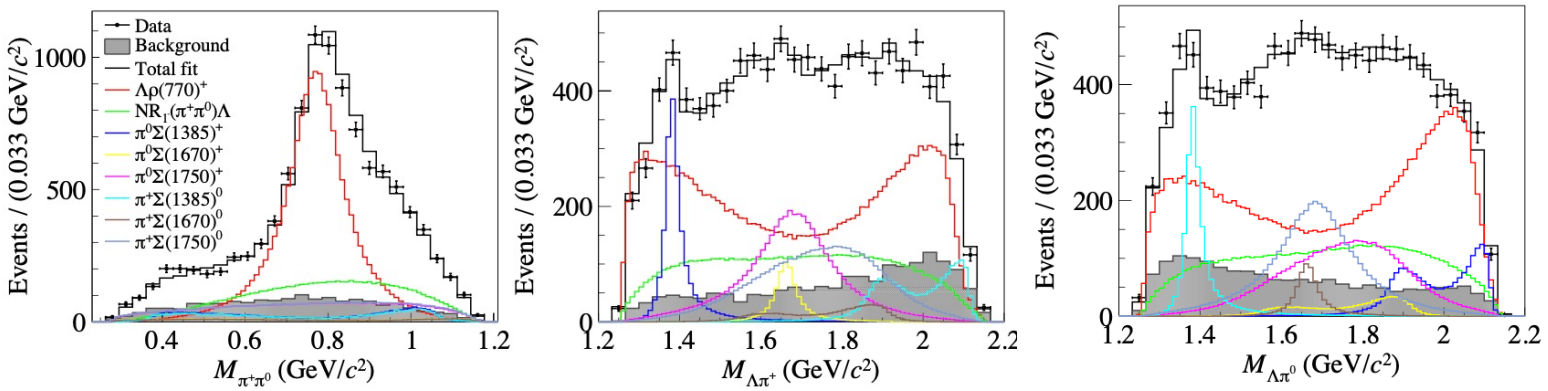


Many CS modes are explored.

Amplitude analysis of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

arXiv:2209.08464

- First Amplitude analysis of this mode
- Based on **TF-PWA** package: ***https://gitlab.com/jiangyi15/tf-pwa***



	Theoretical calculation		This work	PDG
$10^2 \times \mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+)$	4.81 ± 0.58 [13]	4.0 [14, 15]	4.06 ± 0.52	< 6
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	5.86 ± 0.80	—
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	6.47 ± 0.96	—
$\alpha_{\Lambda\rho(770)^+}$	-0.27 ± 0.04 [13]	-0.32 [14, 15]	-0.763 ± 0.066	—
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.917 ± 0.083	—
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.79 ± 0.11	—

Many first measurements of intermediate states!

强子衰变中的CP破坏

To see CPV, need ≥ 2 amplitudes

from Viktor Thoren

Kaons:

Isospin amplitudes $\mathcal{A}_{\Delta I=1/2}$ and $\mathcal{A}_{\Delta I=3/2}$

Test direct CPV via $\frac{\mathcal{A}(K_L\to\pi^0\pi^0)}{\mathcal{A}(K_S\to\pi^0\pi^0)} \equiv \epsilon - 2\epsilon'$, $\frac{\mathcal{A}(K_L\to\pi^+\pi^-)}{\mathcal{A}(K_S\to\pi^+\pi^-)} \equiv \epsilon + \epsilon'$

Hyperons:

Two amplitudes S, P *even* for $\Delta I = 1/2$:

$\mathcal{A} = S + P\sigma\cdot\hat{n}$

Strong phases

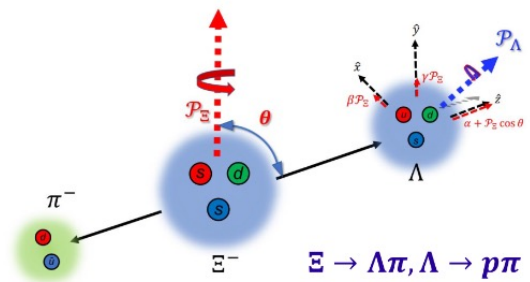
$$S = |S|\exp(i\xi_S)\exp(i\delta_S)$$
$$P = |P|\exp(i\xi_P)\exp(i\delta_P)$$

Weak CP-odd phases

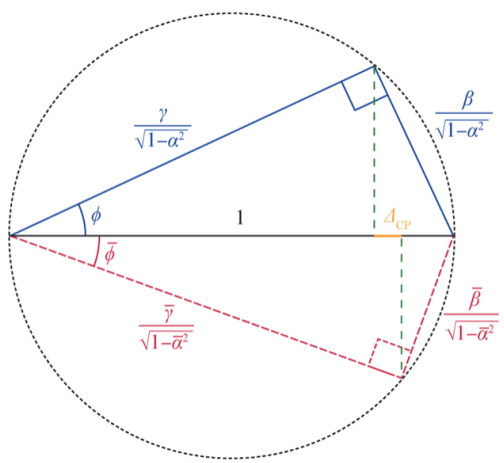
Two Measureable Parameters

$$\alpha = \frac{2Re(S^*P)}{|S|^2+|P|^2}$$
$$\beta = \frac{2IM(S^*P)}{|S|^2+|P|^2} = \sqrt{1-\alpha^2}\sin\phi$$

Experimentally, ϕ accessible when polarization of mother and daughter hyperon measured.



$$\beta = \sqrt{1-\alpha^2}\sin\phi$$



CP-tests: $A_{CP} = \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}}$, $B_{CP} = \frac{\beta+\bar{\beta}}{\alpha-\bar{\alpha}} = (\xi_P - \xi_S)$

SM prediction [1]:

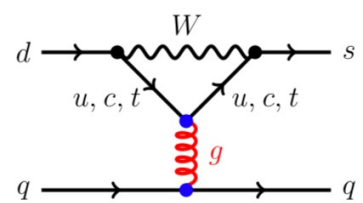
$-3\times10^{-5} \leq A_\Lambda \leq 4\times10^{-5}$

$-2\times10^{-5} \leq A_\Xi \leq 1\times10^{-5}$

Decay mode	$\xi_S - \xi_P$ (10^{-4} rad.)
$\Lambda \to p\pi^-$	0.3 ± 2.2
$\Xi \to \Lambda\pi^-$	-1.9 ± 1.6

HyperCP measurement[2]:

$$A_{CP}^{\Xi} + A_{CP}^{\Lambda} = 0(5)(4)\times10^{-4}$$



$(\xi_P - \xi_S)_{BSM} = \frac{C'_B}{B_G}\left(\frac{\epsilon'}{\epsilon}\right)_{BSM} + \frac{C_B}{\kappa}\epsilon_{BSM}$

$0.5 < B_G < 2$ and $0.2 < |\kappa| < 1$ [3]

Decay	C_B	C'_B
$\Lambda \to p\pi^-$	1.1 ± 2.2	0.4 ± 0.8
$\Xi \to \Lambda\pi^-$	-0.5 ± 1.0	0.4 ± 0.7

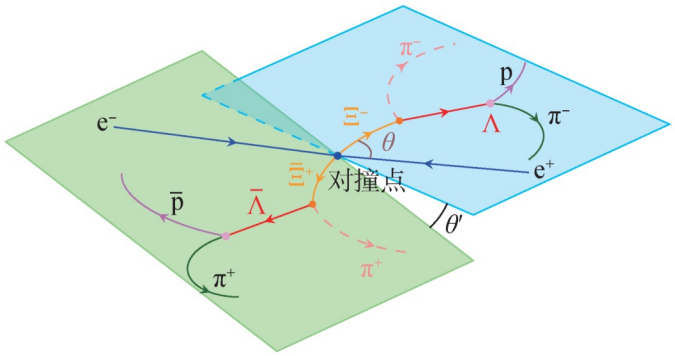
CPV in $\Xi^- \rightarrow \Lambda\pi^-$ decay

Nature 606, 64 (2022)

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

Parameter	This work	Previous result	
α_ψ	$0.586 \pm 0.012 \pm 0.010$	$0.58 \pm 0.04 \pm 0.08$	38
$\Delta\Phi$	$1.213 \pm 0.046 \pm 0.016$ rad.	–	
α_Ξ	$-0.376 \pm 0.007 \pm 0.003$	-0.401 ± 0.010	22
ϕ_Ξ	$0.011 \pm 0.019 \pm 0.009$ rad.	-0.037 ± 0.014 rad.	22
$\alpha_{\bar{\Xi}}$	$0.371 \pm 0.007 \pm 0.002$	–	
$\phi_{\bar{\Xi}}$	$-0.021 \pm 0.019 \pm 0.007$ rad.	–	
α_Λ	$0.757 \pm 0.011 \pm 0.008$	$0.750 \pm 0.009 \pm 0.004$	3
$\alpha_{\bar{\Lambda}}$	$-0.763 \pm 0.011 \pm 0.007$	$-0.758 \pm 0.010 \pm 0.007$	3
$\xi_p - \xi_s$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad.	–	
$\delta_p - \delta_s$	$(-4.4 \pm 3.6 \pm 1.8) \times 10^{-2}$ rad.	$(8.7 \pm 3.3) \times 10^{-2}$ rad.	2
A_{CP}^{Ξ}	$(6.0 \pm 13.4 \pm 5.6) \times 10^{-3}$	–	
$\Delta\phi_{CP}^{\Xi}$	$(-4.8 \pm 13.7 \pm 2.9) \times 10^{-3}$ rad.	–	
A_{CP}^{Λ}	$(-3.7 \pm 11.7 \pm 9.0) \times 10^{-3}$	$(-6 \pm 12 \pm 7) \times 10^{-3}$	3
$\langle \phi_\Xi \rangle$	$0.016 \pm 0.014 \pm 0.007$ rad.		

Based on 1.3 B J/ψ events (13% of total J/ψ events)
9-dimentional fit: ~73K signals



First measurement of baryon weak phase difference

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

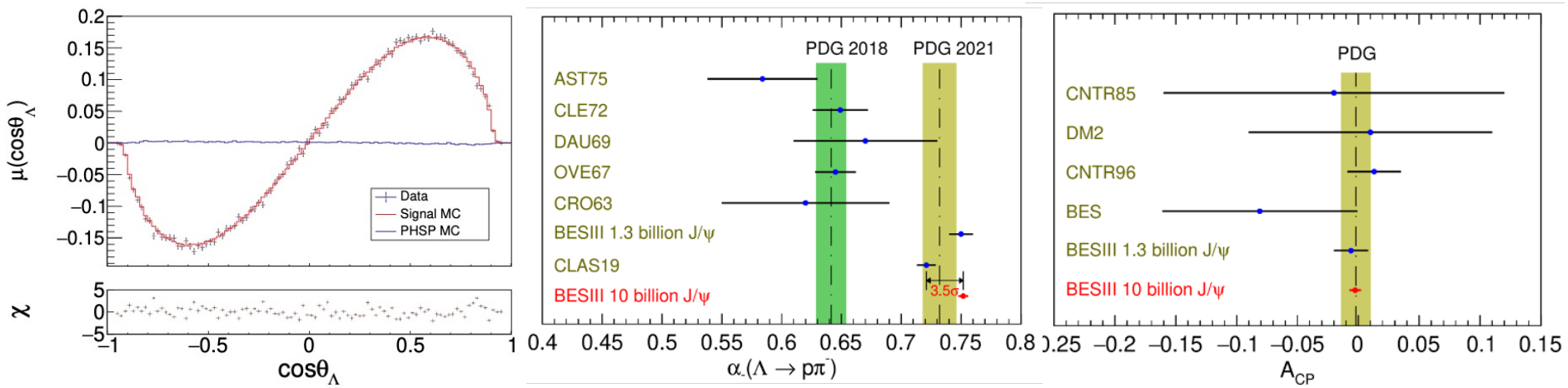
HyperCP: $\phi_{\Xi,HyperCP} = -0.042 \pm 0.011 \pm 0.011$
BESIII: $\langle\phi_\Xi\rangle = 0.016 \pm 0.014 \pm 0.007$

HyperCP: PRL 93(2004) 011802

Updated Λ decay asymmetry in $J/\psi \to \Lambda\bar{\Lambda}$

PRL129, 131801(2022)

- Updated results based on 10B J/ψ events: ~0.42M signals
- Perfect fit to data
- Decay asymmetries with improved precisions are consistent with previous BESIII results
- Sensitivity of A_{CP} is improved to the level of below 0.5%

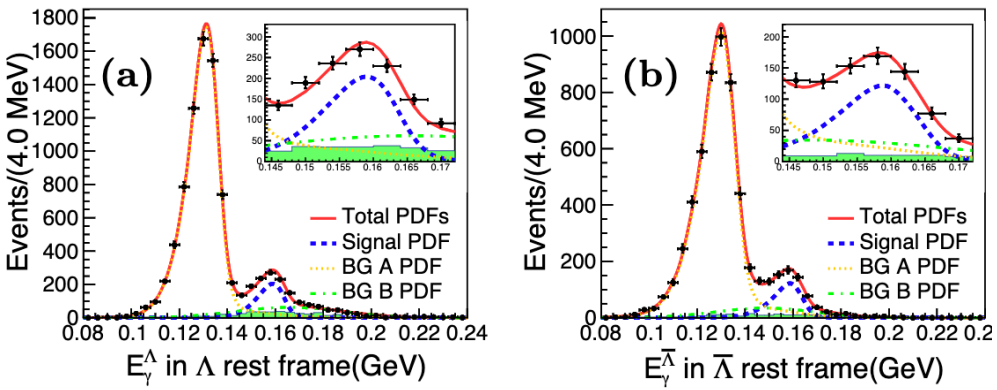


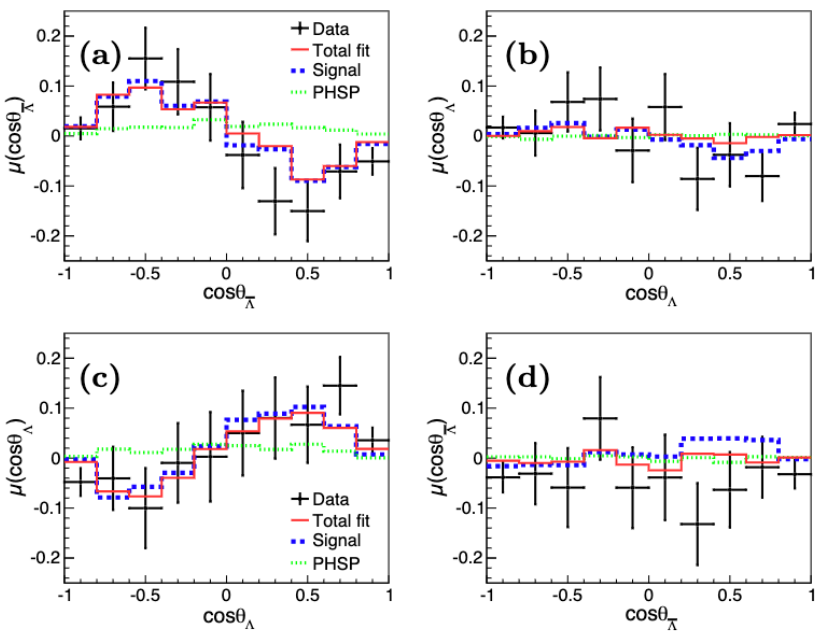
Par.	This Work*	Previous results **	PDG 2018 ***
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0024$	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0080$	$0.740 \pm 0.010 \pm 0.009$	-
α_-	$0.7519 \pm 0.0036 \pm 0.0019$	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013
α_+	$-0.7559 \pm 0.0036 \pm 0.0029$	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0011$	$0.006 \pm 0.012 \pm 0.007$	-
$\alpha_{\pm,avg.}$	$0.7542 \pm 0.0010 \pm 0.0020$	$0.754 \pm 0.003 \pm 0.002$	-

Radiative hyperon decay $\Lambda \to \gamma n$ in $J/\psi \to \Lambda\bar{\Lambda}$ decays

arXiv:2206.10791

- To access the information on parity violating and parity conserving amplitudes in hyperon decays
- Previous measurements are from fixed target experiments and 30 years old!





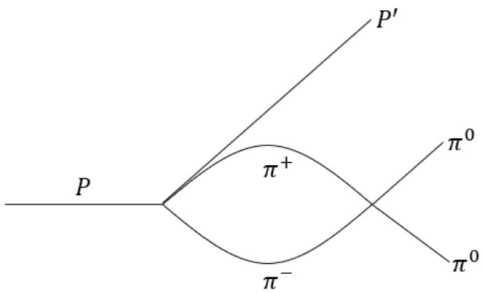
Decay Mode	$\Lambda \to n\gamma$	$\bar{\Lambda} \to \bar{n}\gamma$
BF ($\times 10^{-3}$)	$0.820 \pm 0.045 \pm 0.066$	$0.862 \pm 0.071 \pm 0.084$
	$\mathbf{0.832 \pm 0.038 \pm 0.054}$	
α_γ	$-0.13 \pm 0.13 \pm 0.03$	$0.21 \pm 0.15 \pm 0.06$
	$\mathbf{-0.16 \pm 0.10 \pm 0.05}$	

- A factor of two smaller than the previous measurement
- Obtained asymmetry does not agree well with existing theoretical predictions

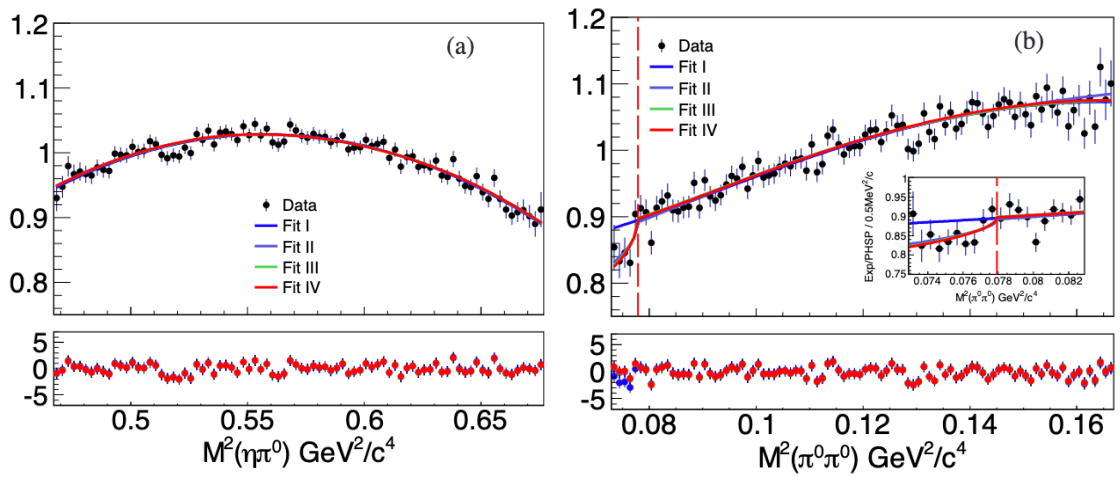
Evidence for the cusp effect in $\eta' \to \eta\pi^0\pi^0$

arXiv:2207.01004

- Based on 10B J/ψ events: ~0.43M signals of $\eta' \to \eta\pi^0\pi^0$
- A Dalitz plot analysis within the framework of non-relativistic effective field theory (NREFT)



$$C_{00} = \frac{16\pi}{3}(a_0 + 2a_2)(1-\xi),$$
$$C_x = \frac{16\pi}{3}(a_2 - a_0)(1+\frac{\xi}{3}),$$
$$C_{+-} = \frac{8\pi}{3}(2a_0 + a_2)(1+\xi),$$
$$\xi = \frac{M^2_{\pi^\pm} - M^2_{\pi^0}}{M^2_{\pi^\pm}}.$$

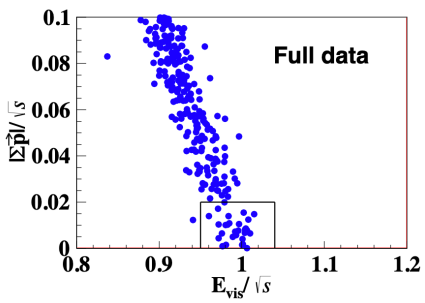


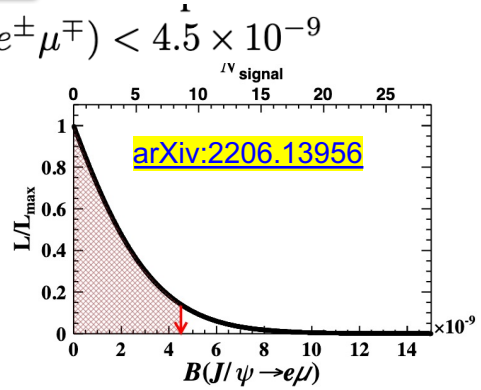
- Evidence for a structure at $\pi^+\pi^-$ mass threshold is observed in the $\pi^0\pi^0$ mass spectrum with a statistical significance of around 3.5σ
  ➔ consistent with the cusp effect as predicted by the non-relativistic effective field theory
- Scattering length combination $a_0 - a_2$ determined to be $0.226 \pm 0.060 \pm 0.012$
  ➔ in good agreement with theoretical calculation of 0.2644 ± 0.0051

Rare processes

LFV in $J/\psi \to e^+\mu^-$

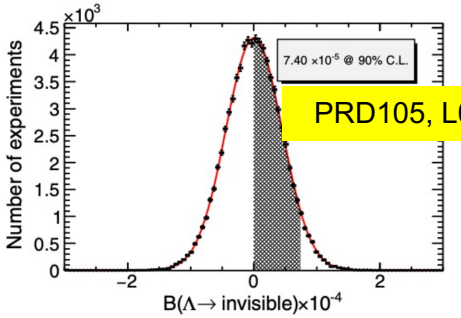
$$\mathcal{B}(J/\psi \to e^{\pm}\mu^{\mp}) < 4.5 \times 10^{-9}$$



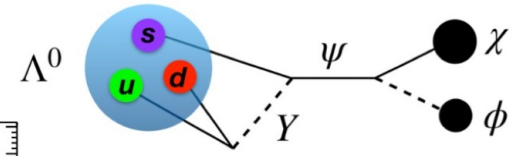


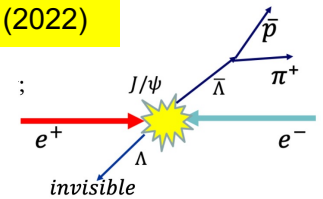
arXiv:2206.13956

Λ invisible decays



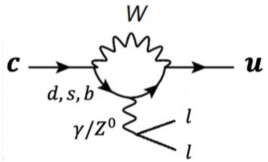
PRD105, L071101(2022)



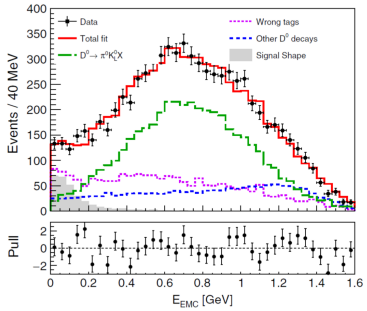


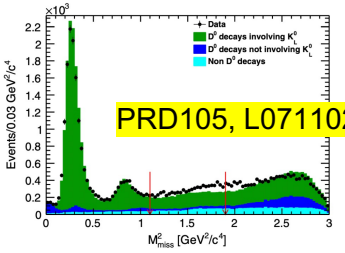
$\mathcal{B}(\Lambda \to invisible) < 7.4\times10^{-5}$

$D^0 \to \pi^0\nu\bar{\nu}$



- $\mathcal{B}(D^0 \to \pi^0\nu\bar{\nu}) < 2.1\times10^{-4}$
- FCNC is forbidden in SM at tree level but allowed in loop/box diagrams.
- Discriminator: EMC energy not associated with signal and tag decays.
- Provide a clean probe to search for New Physics in charm sector.



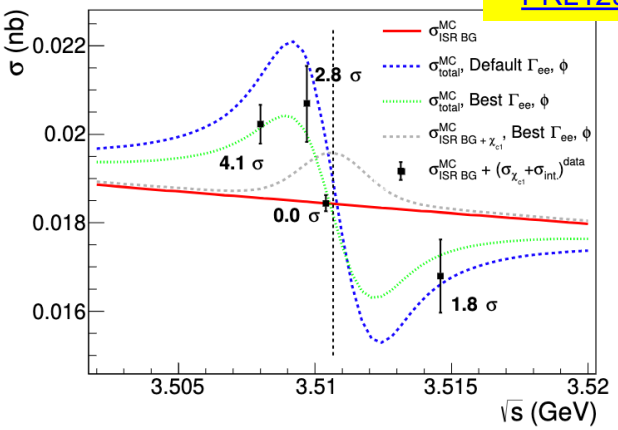


PRD105, L071102(2022)

Observation of $e^+e^- \to \chi_{c1}$

$$\Gamma_{ee} = (0.12^{+0.13}_{-0.08})\ \text{eV}.$$

PRL129, 122001 (2022)

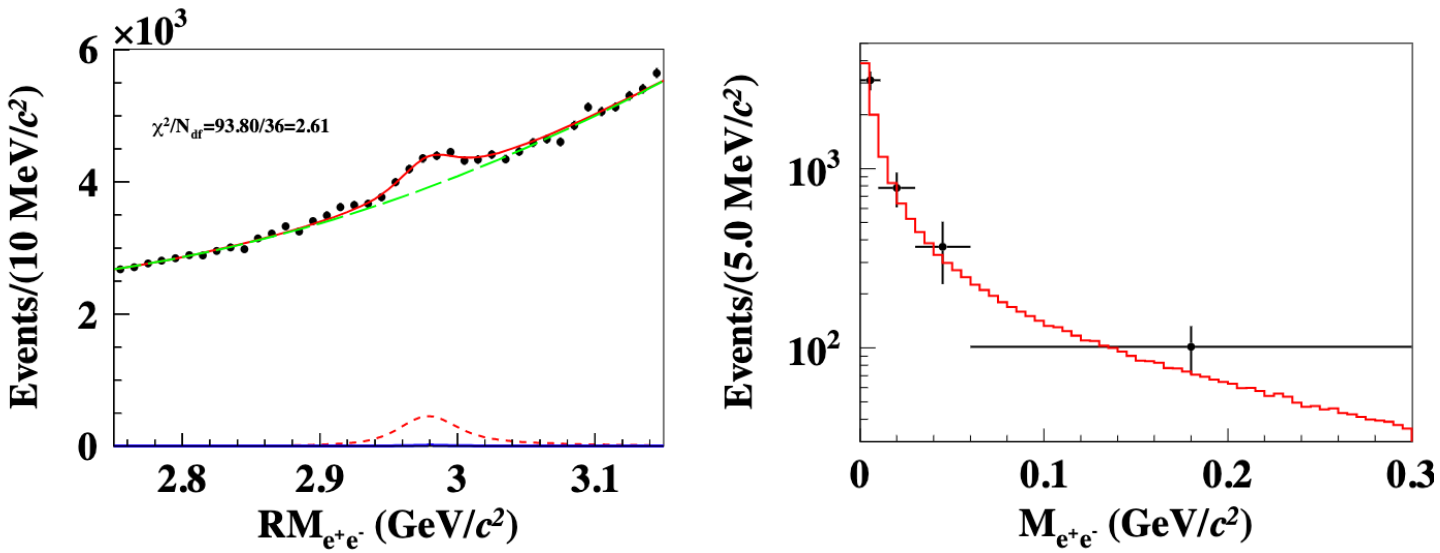


Observation of the hindered electromagnetic Dalitz decay $\psi(3686) \to e^+e^-\eta_c$

arXiv:2208.12241

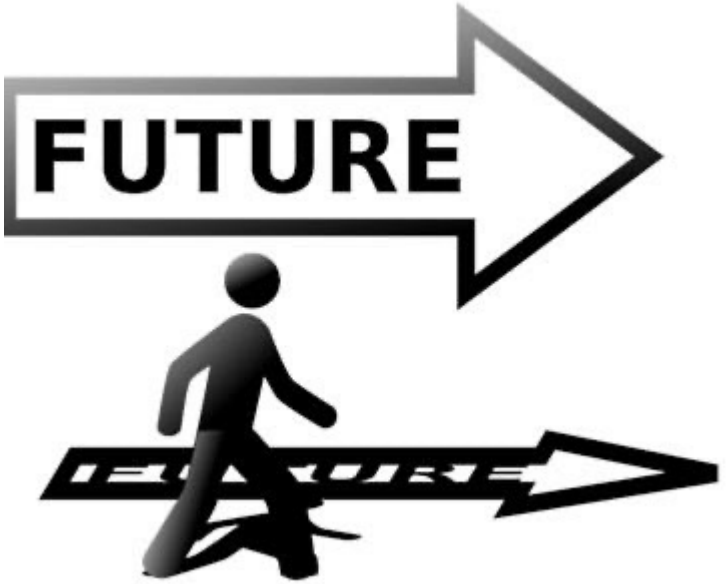
- A probe of the dynamic EM structure of the transition V→P, to investigate the fundamental mechanisms for the interactions between photons and hadrons
- Transition form factor characterizes the EM structure

$$\frac{d\Gamma(V \to \ell^+\ell^- P)}{dq^2\Gamma(V \to \gamma P)} = \left|\frac{f_{VP}(q^2)}{f_{VP}(0)}\right|^2 \times \mathrm{QED}(q^2)$$

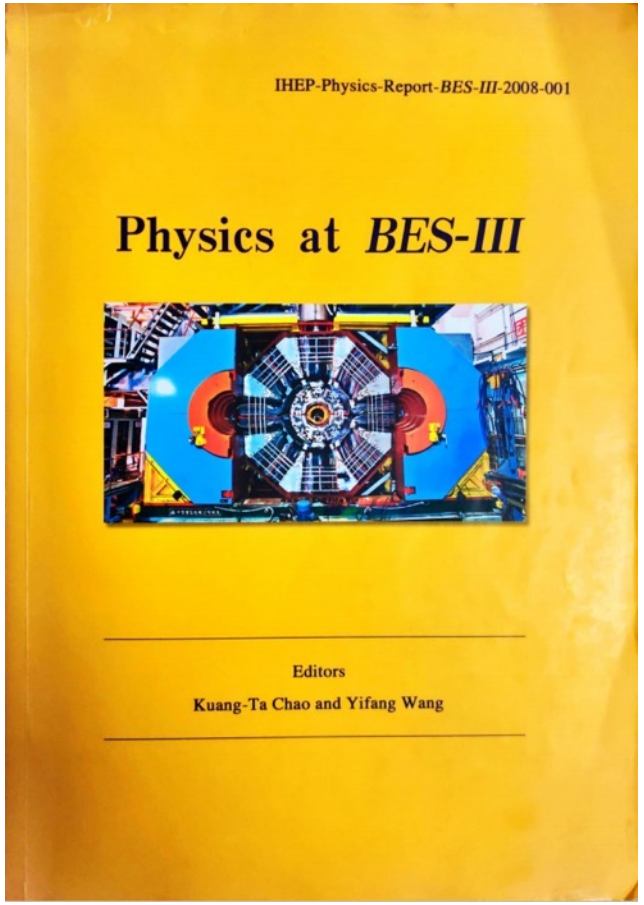


$$\mathcal{B}(\psi(3686) \to e^+e^-\eta_c) = (3.77 \pm 0.40_{\text{stat.}} \pm 0.18_{\text{syst.}}) \times 10^{-5}$$

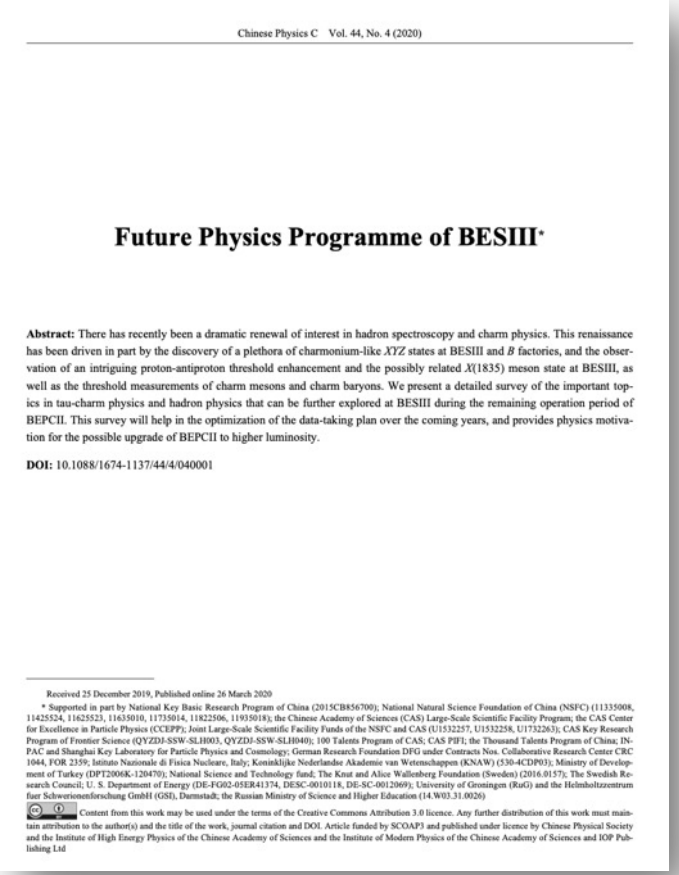
consistent with the theoretical prediction from the VMD model


FUTURE

BESIII Physics



Int. J. Mod. Phys. A 24, S1-794 (2009) [arXiv:0809.1869 [hep-ex]].



Chinese Physics C Vol. 44, No. 4 (2020)

Future Physics Programme of BESIII*

Abstract: There has recently been a dramatic renewal of interest in hadron spectroscopy and charm physics. This renaissance has been driven in part by the discovery of a plethora of charmonium-like XYZ states at BESIII and B factories, and the observation of an intriguing proton-antiproton threshold enhancement and the possibly related $X(1835)$ meson state at BESIII, as well as the threshold measurements of charm mesons and charm baryons. We present a detailed survey of the important topics in tau-charm physics and hadron physics that can be further explored at BESIII during the remaining operation period of BEPCII. This survey will help in the optimization of the data-taking plan over the coming years, and provides physics motivation for the possible upgrade of BEPCII to higher luminosity.

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Chin. Phys. C 44, 040001 (2020) doi:10.1088/1674-1137/44/4/040001 [arXiv:1912.05983 [hep-ex]].

Planned future data set

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 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/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
✓ $\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^\pm$ decays	2.9 fb^{-1}	20.0 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 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\Lambda_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\Sigma_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

to be complete in 2022-23

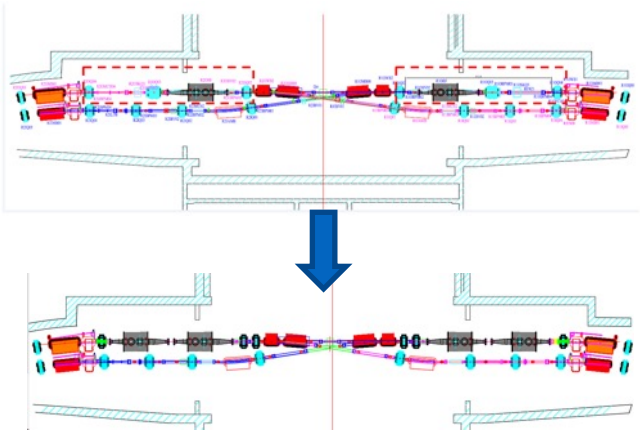
~55 fb^{-1}

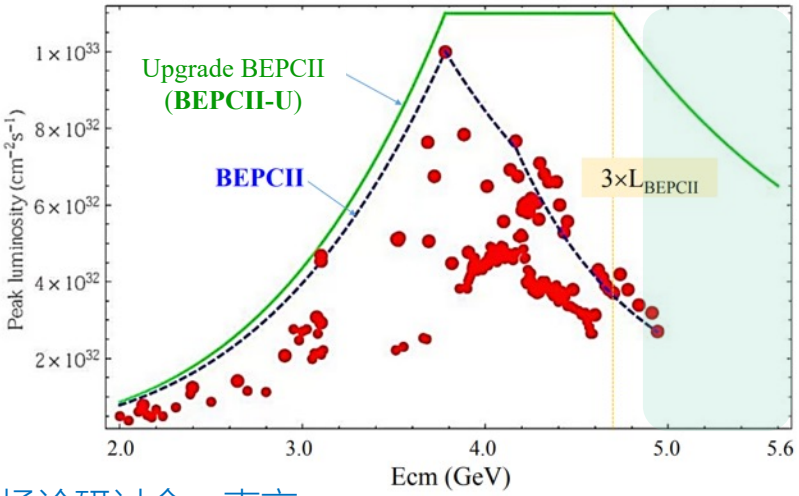
Proposal of the upgrade BEPCII

✓ 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

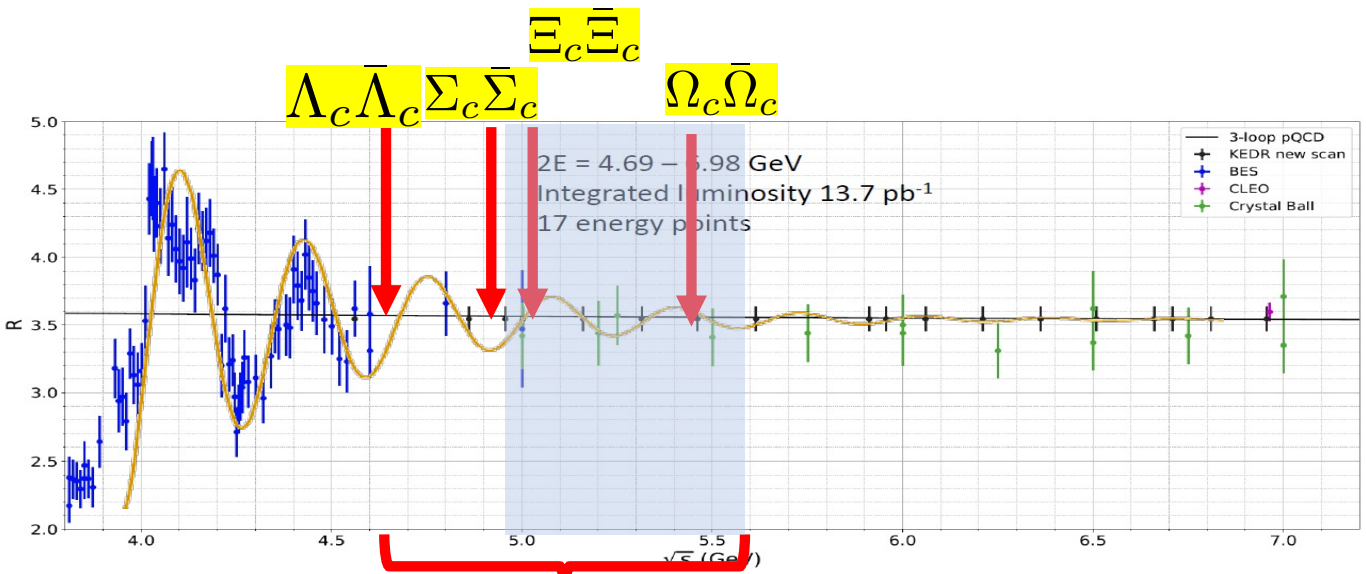
	BEPCII	BEPCII-U
Lum [10^{32}cm^{-2}s^{-1}]	3.5	11
β_y^* [cm]	1.5	1.35
Bunch Current [mA]	7.1	7.5
Bunch Num	56	120
SR Power [kW]	110	250
$\xi_{y,\mathrm{lum}}$	0.029	0.033
Emittance [nmrad]	147	152
Coupling [%]	0.53	0.35
Bucket Height	0.0069	0.011
$\sigma_{z,0}$ [cm]	1.54	1.07
σ_z [cm]	1.69	1.22
RF Voltage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





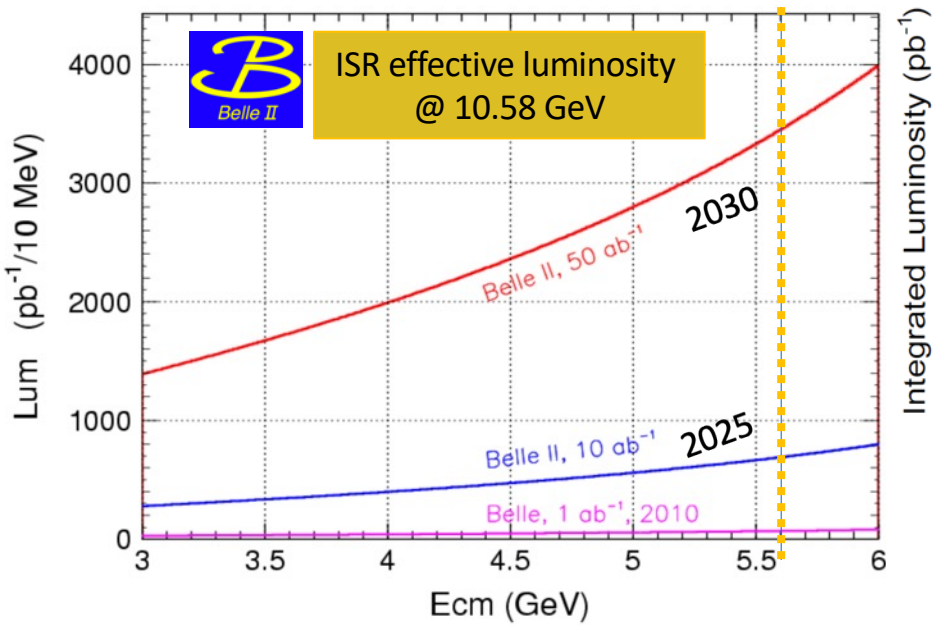
Potential physics with BEPCII-U

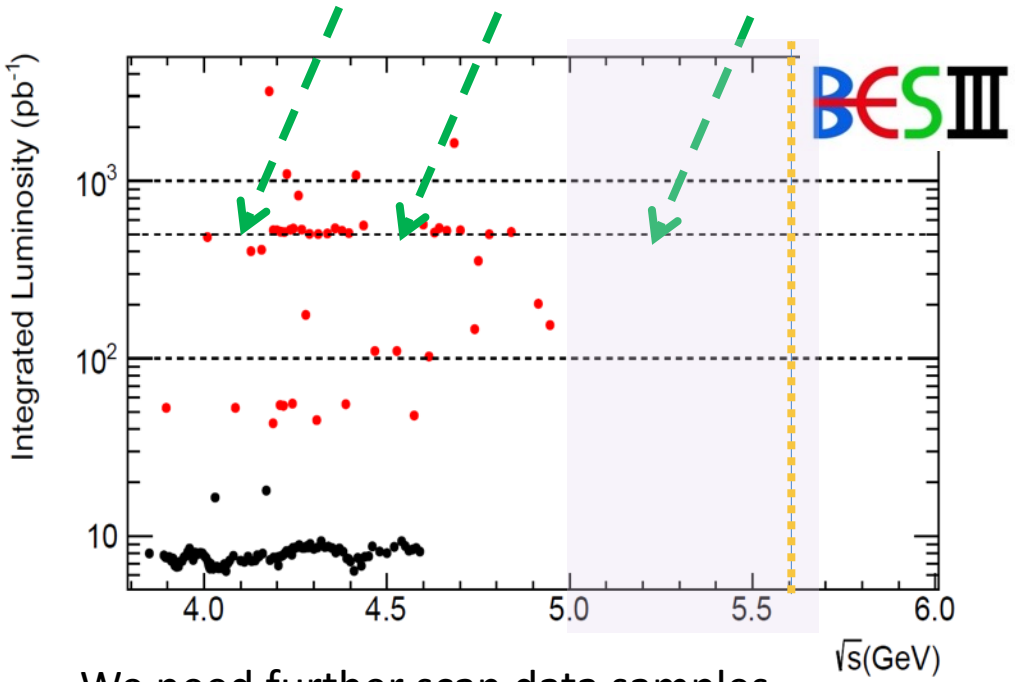
- ✓ Detailed studies of the known $Z_{c(s)}$ states and search for `black swans` in the higher energy region within a considerable amount of data sets.
- ✓ Cover all the ground-state charmed baryons: production & decays, CPV search



Few data and potential physics for XYZ and charmed baryons

Some (personal) thoughts for future data taking





Competition with Belle II exists, and the scan energy points between 4.0 and 5.6 GeV need to be optimized

We need further scan data samples for Ecm=4.00-4.15, 4.43-4.59, 4.90-5.60 GeV, and some other energy points around charmed baryon threshold, such as

- ✓ 4.01 GeV: DsDs
- ✓ 4.6-4.7 GeV: $\Lambda_c\,\bar{\Lambda}_c$
- ✓ 4.95 -4.97GeV: $\Xi_c\,\bar{\Xi}_c$
  5.4 -5.6 GeV: $\Omega_c^0\bar{\Omega}_c^0$

Summary

- BESIII is successfully operating since 2008, and will continue to run for 5–10 years
  – collect large data samples in the energy range 2.0~5.6 GeV
- Cover a large scope of physics topics
  - ✓ Charmed mesons and baryons
  - ✓ XYZ states and light hadron spectroscopy
  - ✓ Form factors of the nucleon and hyperons
  - ✓ Low-Q^2 QCD studies: R value, multi-meson production, fragmentation function, …
  - ✓ Rare decays and new physics search
  - ✓ …
- **Future goals:**
  50M D0, 50M D+, 15M Ds, 2M Λc , high-lumi. fine scan between 3.8 GeV and 5.6 GeV
  ➔ BEPCII-U: 3x upgrade on luminosity

Thank you!

谢谢！