Selected results from the BESIII experiment

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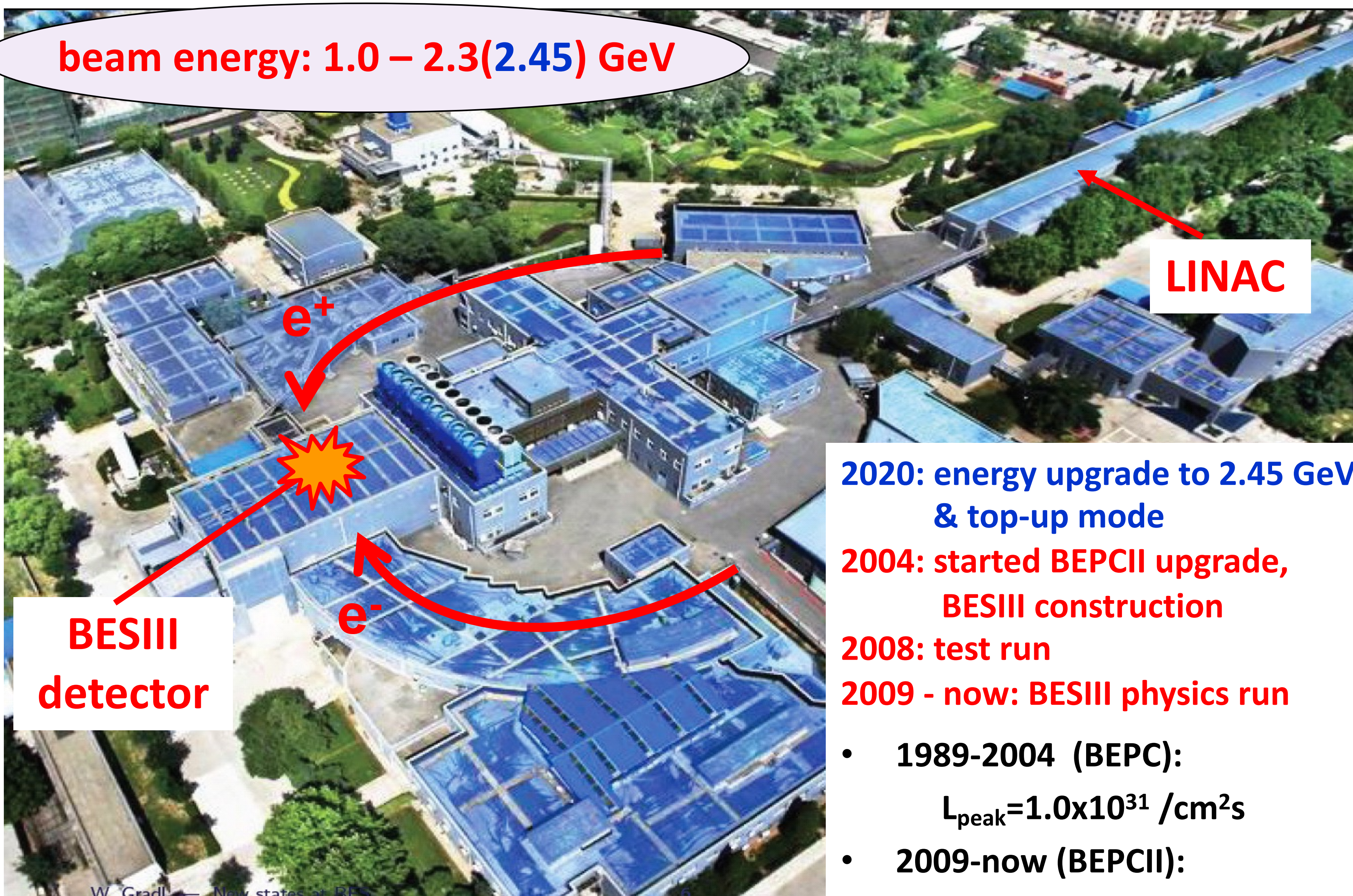
(On behalf of the BESIII collaboration)

Outline

- Introduction
- Selected recent results
- Prospects for the future
- Summary

Beijing Electron Positron Collider (BEPCII)



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

2004: started BEPCII upgrade, BESIII construction

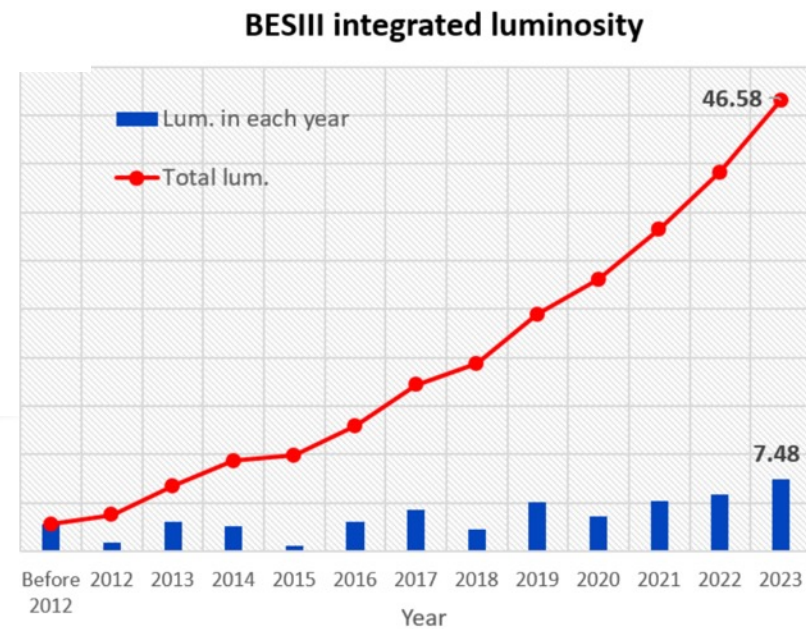
2008: test run

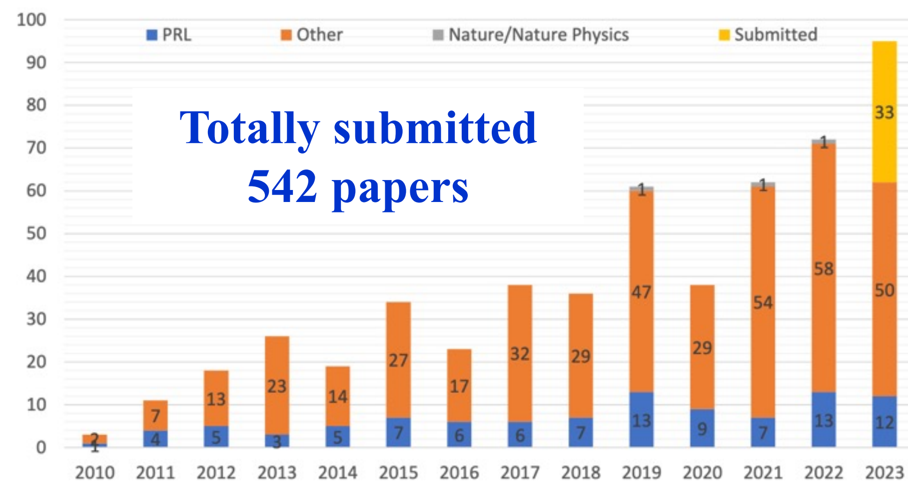
2009 - now: BESIII physics run

- 1989-2004 (BEPC): L_{peak}=1.0x10^{31} /cm^2s
- 2009-now (BEPCII): L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

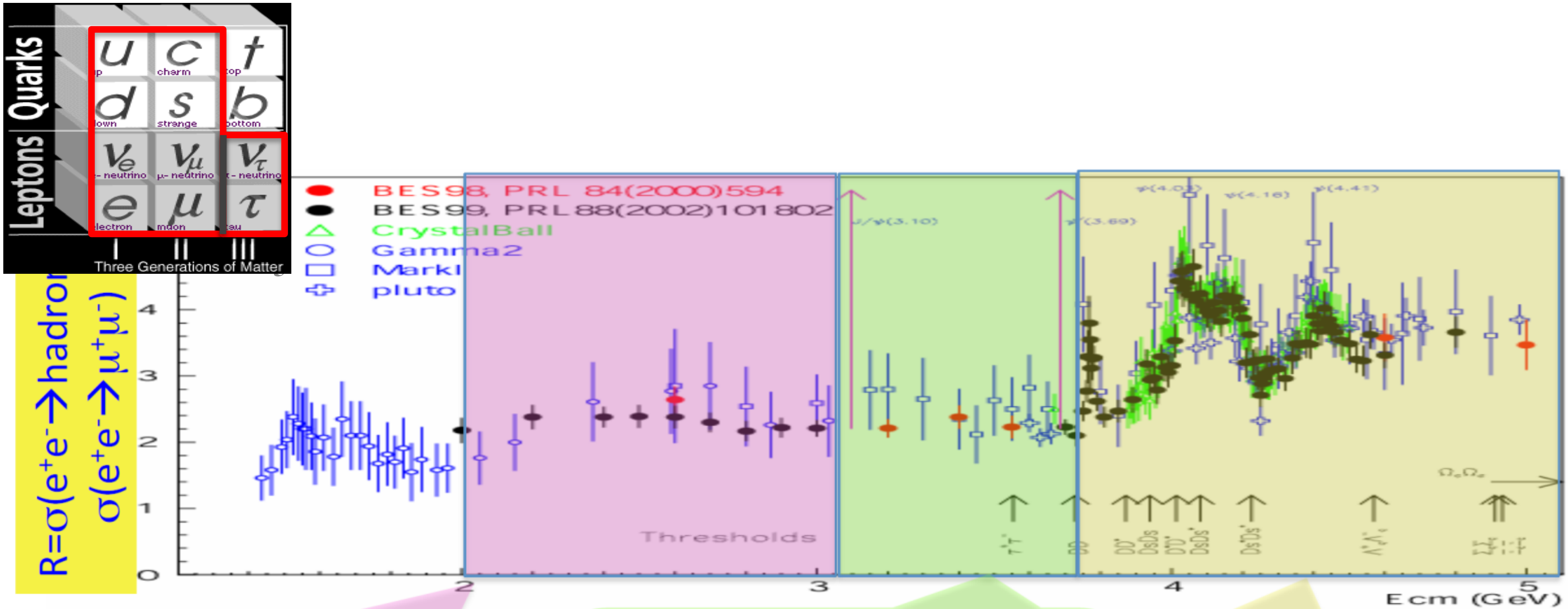
BESIII data sample

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 $\psi(3770)$
2023: ~8.1 fb^{-1} will be taken at $\psi(3770)$





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

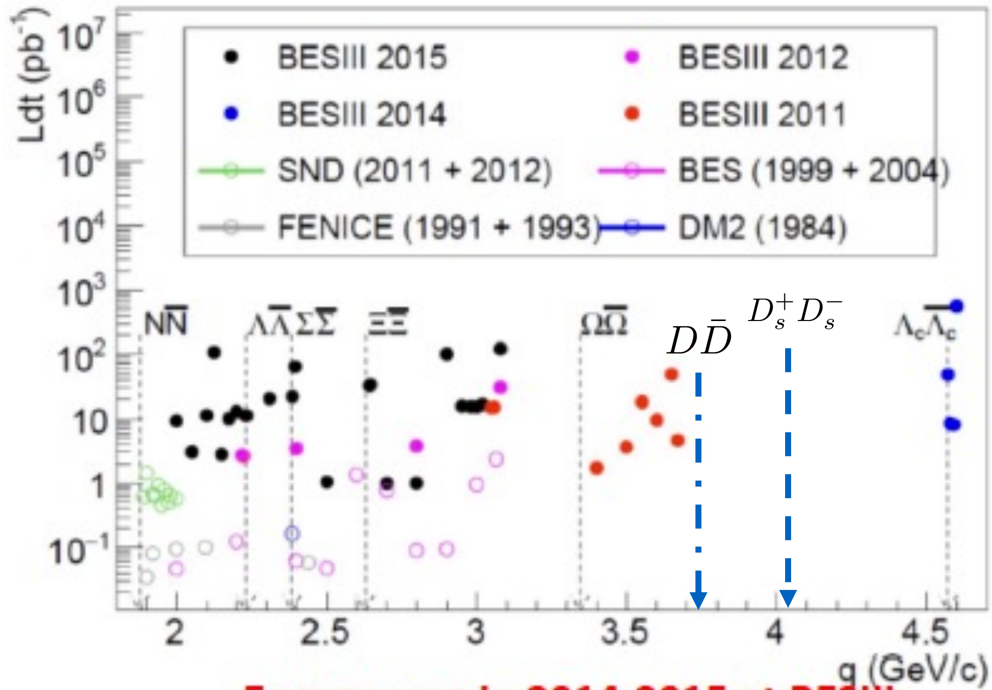
- XYZ particles
- D mesons
- f_D and f_{D_s}
- D_0-D_0 mixing
- Charm baryons

Precision measurement

Unique data sets near thresholds

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

3.773 GeV, ~16 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

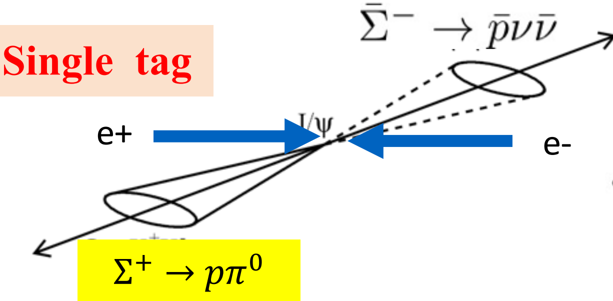
Known beam energy: pair productions

Decay with neutron & π^0

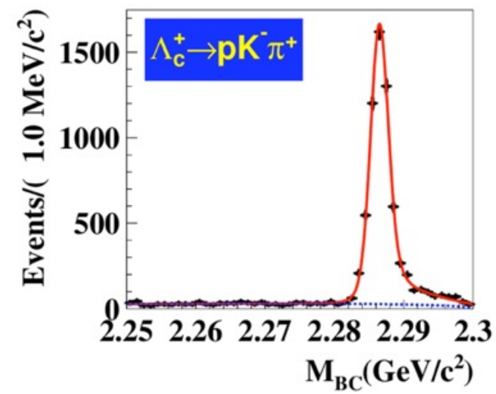
Decay with invisibles: neutrinos

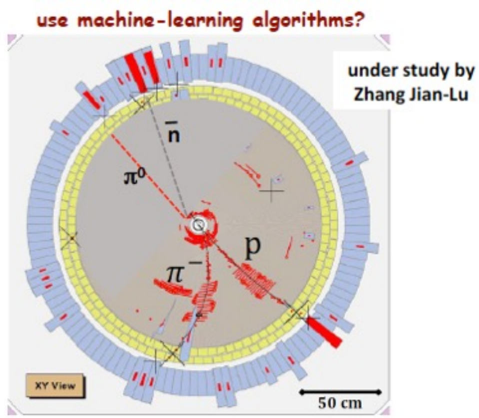
Missing mass or missing energy

Single tag

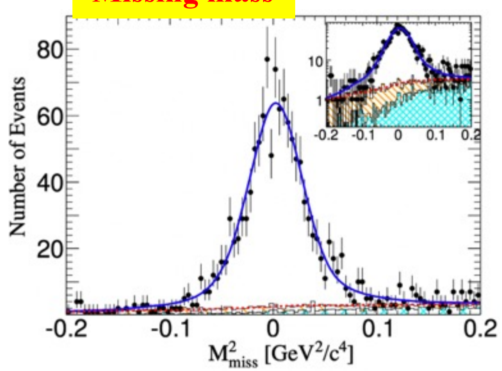


Excellent resolution
Beam-constraint Λ_c mass

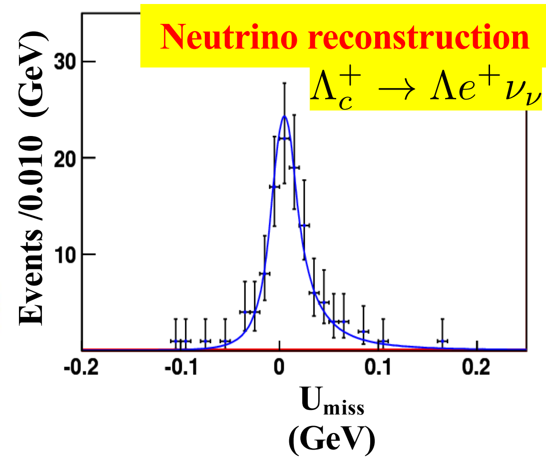


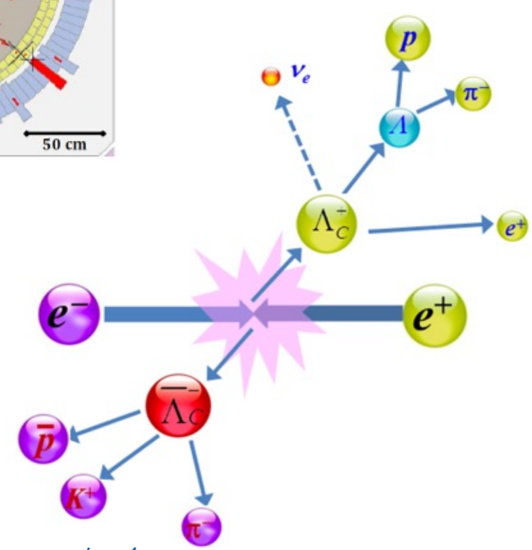


Missing mass

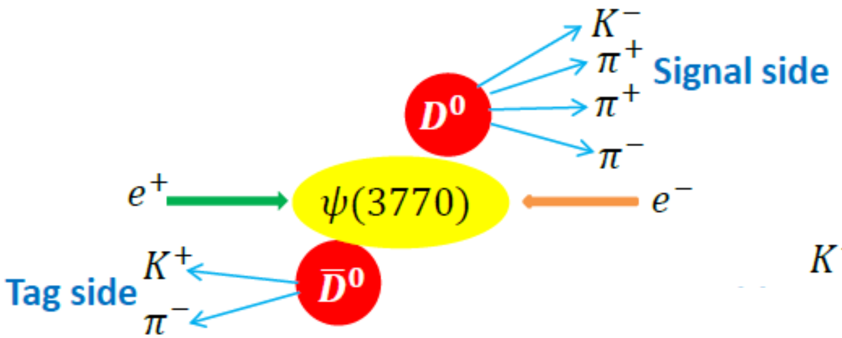


Neutrino reconstruction

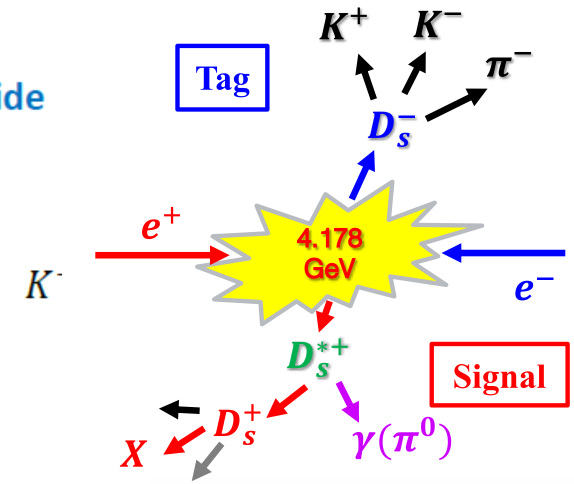


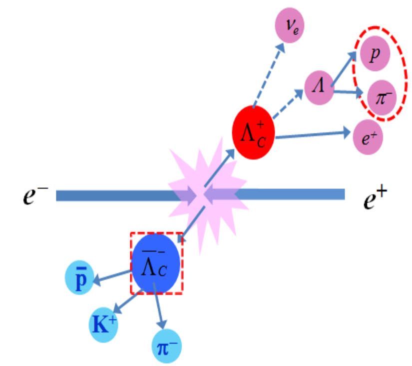


Charm hadron decays



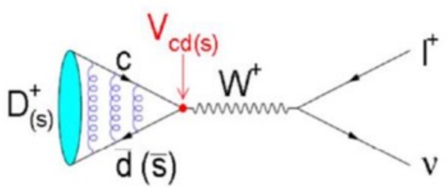
2.93/fb at $\psi(3770)$



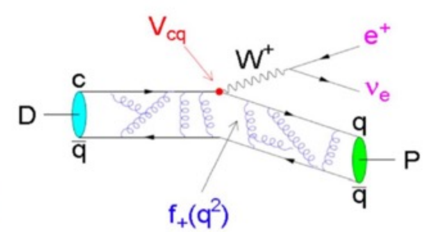


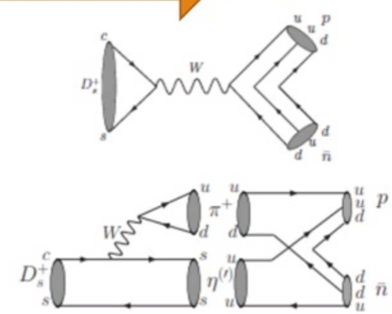
0.567/fb at 4.6 GeV

COMPLEXITY



$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D^+_{(s)}}^2}{8\pi} |V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m_{D^+_{(s)}}^2}\right)^2$$





Purely Leptonic	Semi Leptonic	Hadronic
Take V_{cx} from fits to CKM assuming unitarity and measure f Precise test of lattice QCD in charm and extrapolate to beauty	Similar to leptonic decay but now q (= four-momentum of W) dependent Test QCD models of the form factor	Models of hadronic decay • Isospin • SU(3) flavour • Different amplitudes T, P, A, E • Long and short distance effects

Precision measurement of CKM elements -- Test EW theory

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix

BESIII + B factories + LQCD

Three generations of quark?

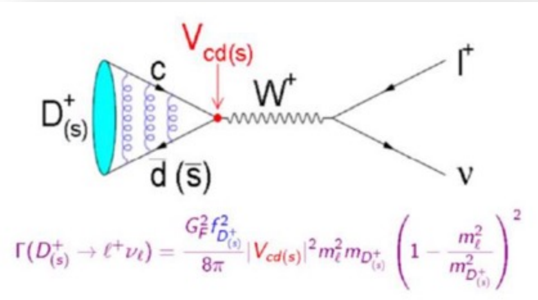
Unitary matrix?

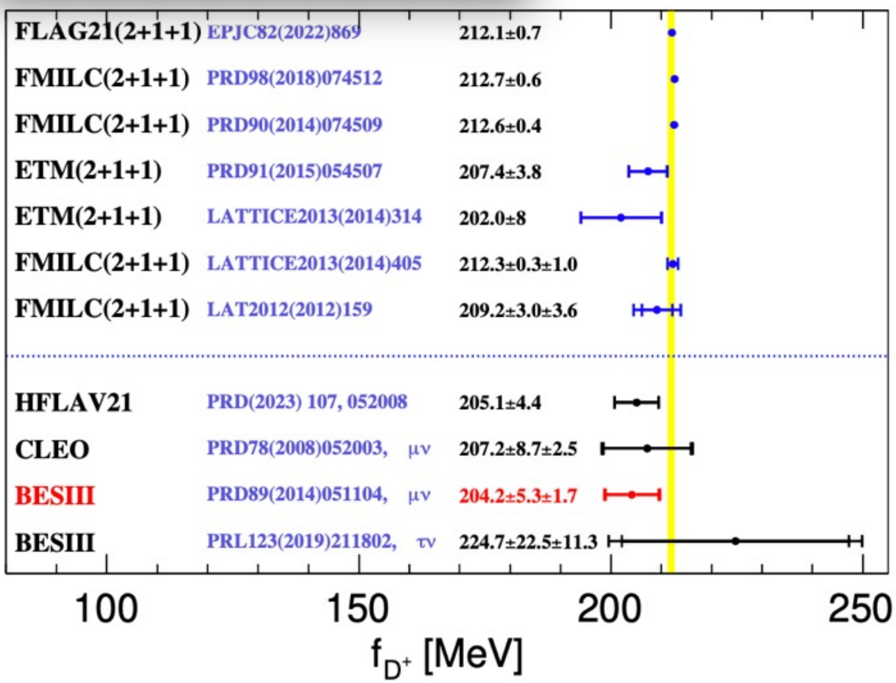
Expected precision < 2% at BESIII

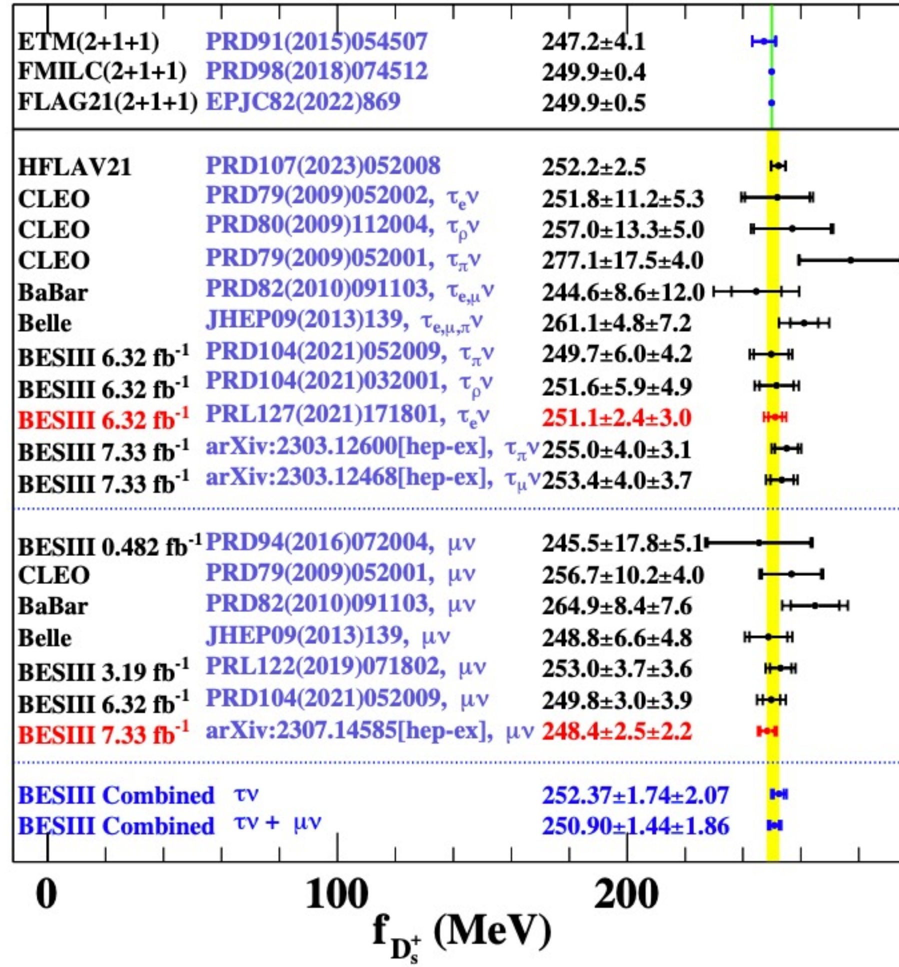
BESIII + B factories + LHCb + LQCD

- **Precision measurement of CKM matrix elements**
- **A precise test of SM model**
- **New physics beyond SM?**

$D^+_{(s)}$ decay constant

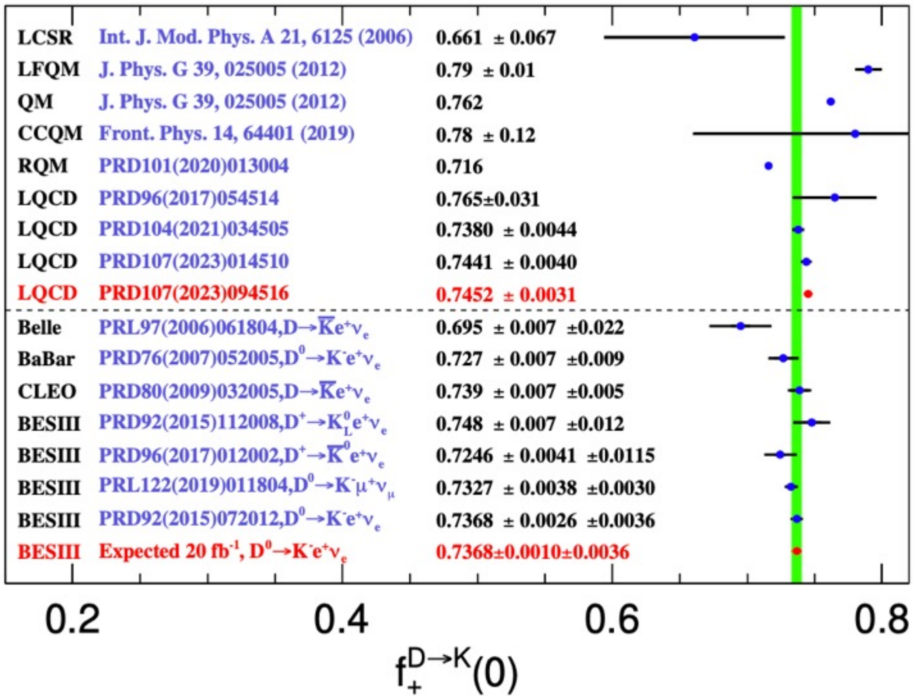


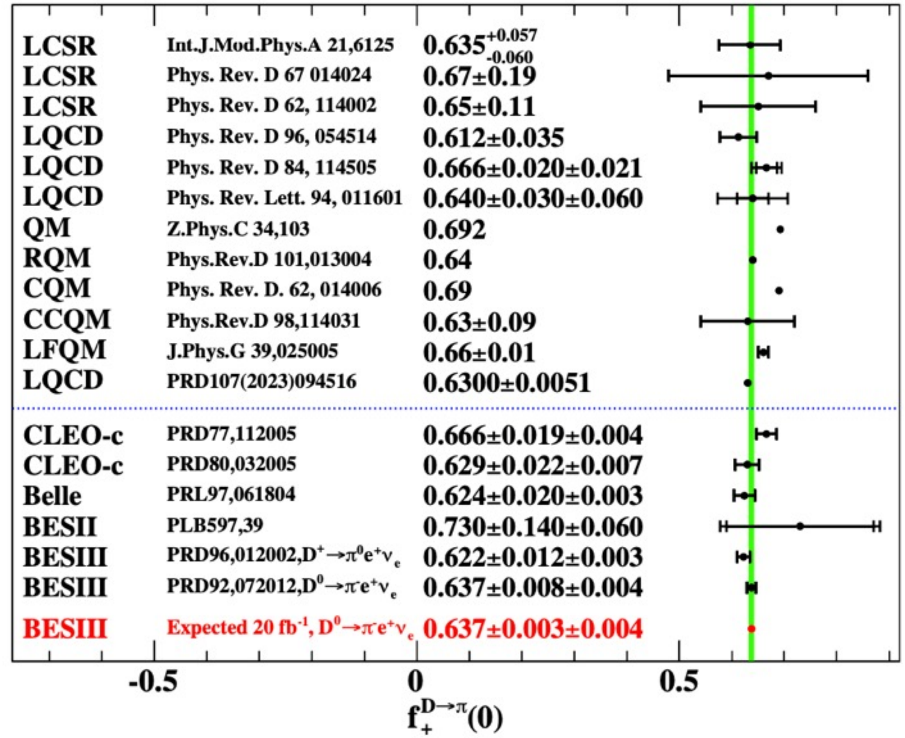


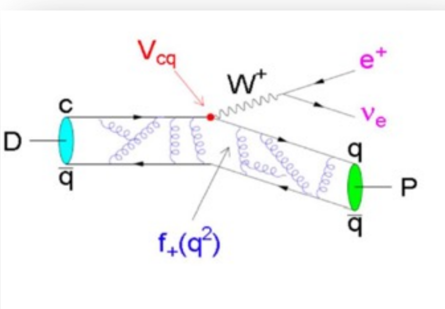


- Highest precision for f_{D+} in single decay mode: $D^+ \to \mu^+\nu_\mu$: 2.7% (2.93 fb^{-1})→1.8% (7.9 fb^{-1})→1.3% (20 fb^{-1})
- Highest precision for $f_{D_s^+}$: 1.3% (7.33 fb^{-1} $D_s^+ \to \mu^+\nu_\mu$)→ 0.9% (Combine all $D_s^+ \to \ell^+\nu_\ell$)

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

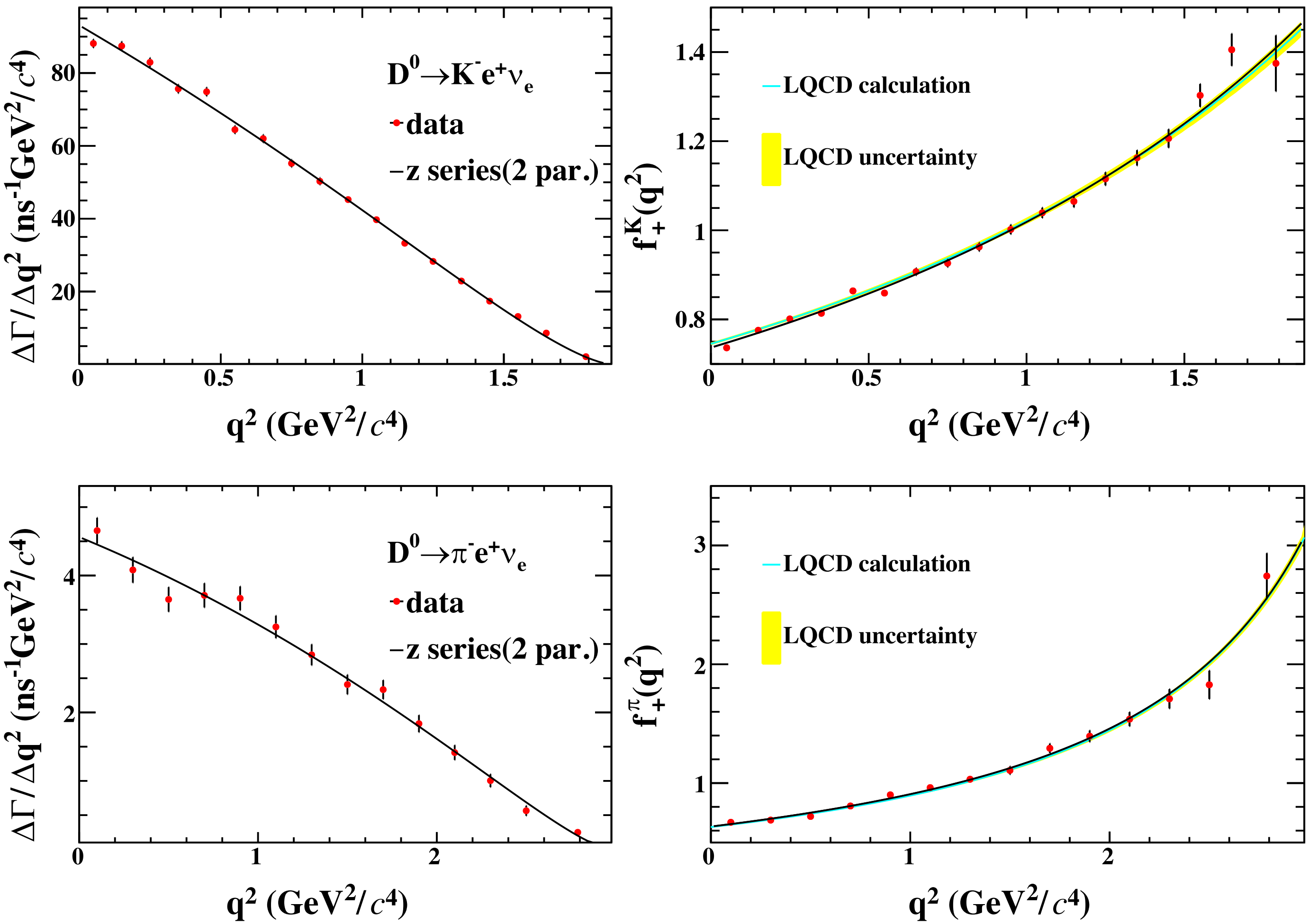






- LQCD has repaid improvement on precisions
- Systematics on from factors at BESIII will be dominant and crucial for further 20/fb charm data

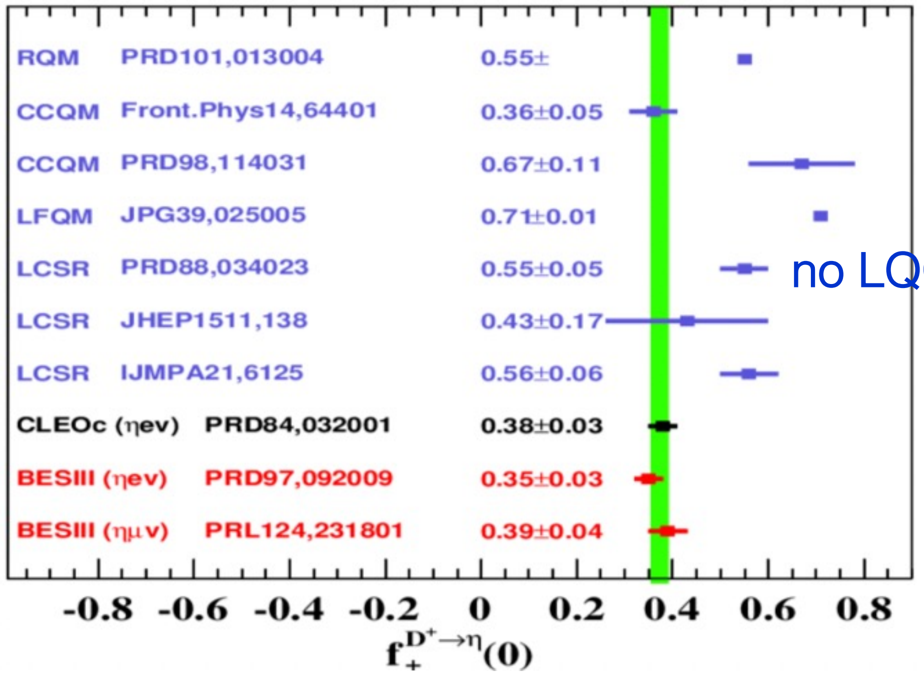
Energy-dependent form factors



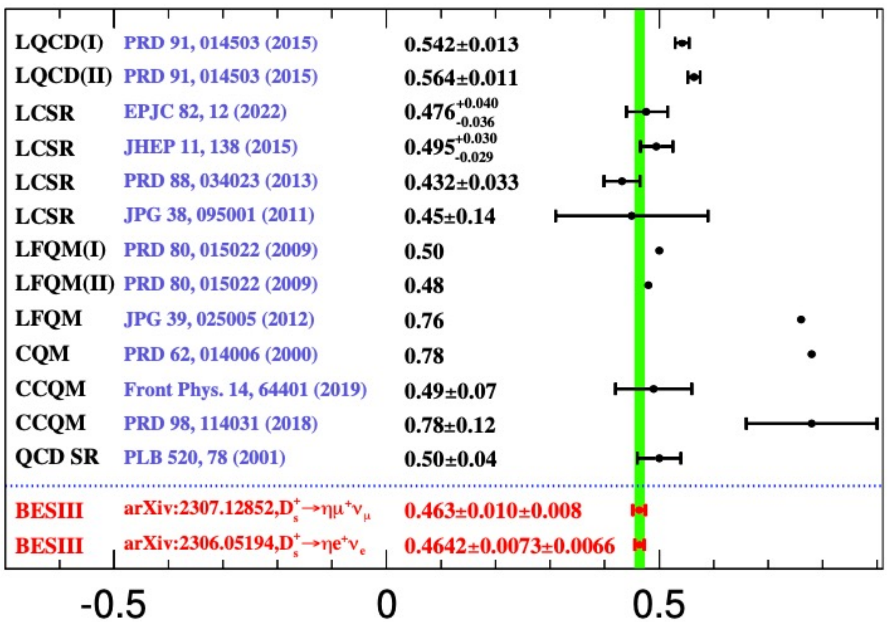
data: BESIII, PRD 92, 072012 (2015)]
LQCD: PRD 107, 094516 (2023)

amazing agreement

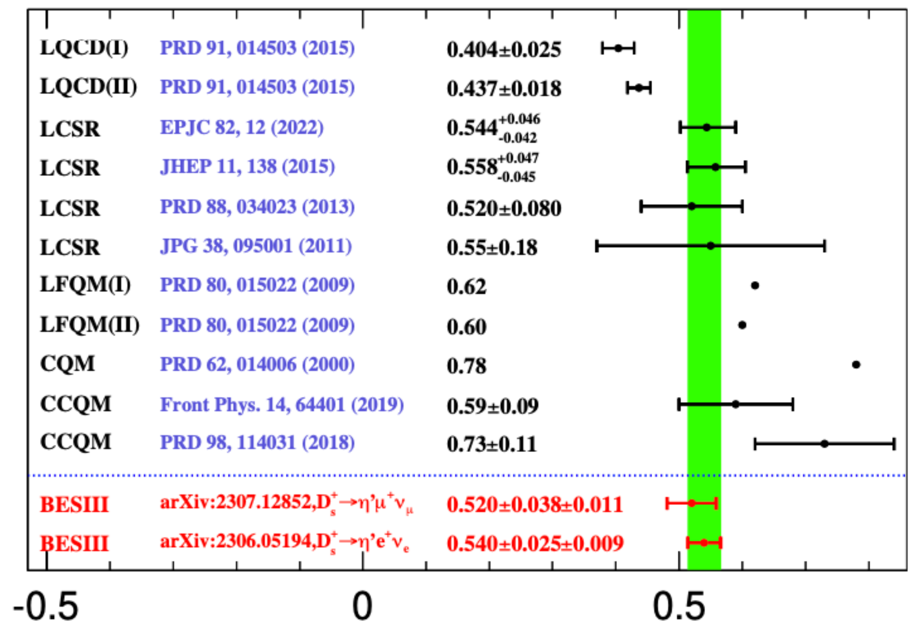
$\eta^{(\prime)}$ semileptonic mode



no LQCD result yet (?)



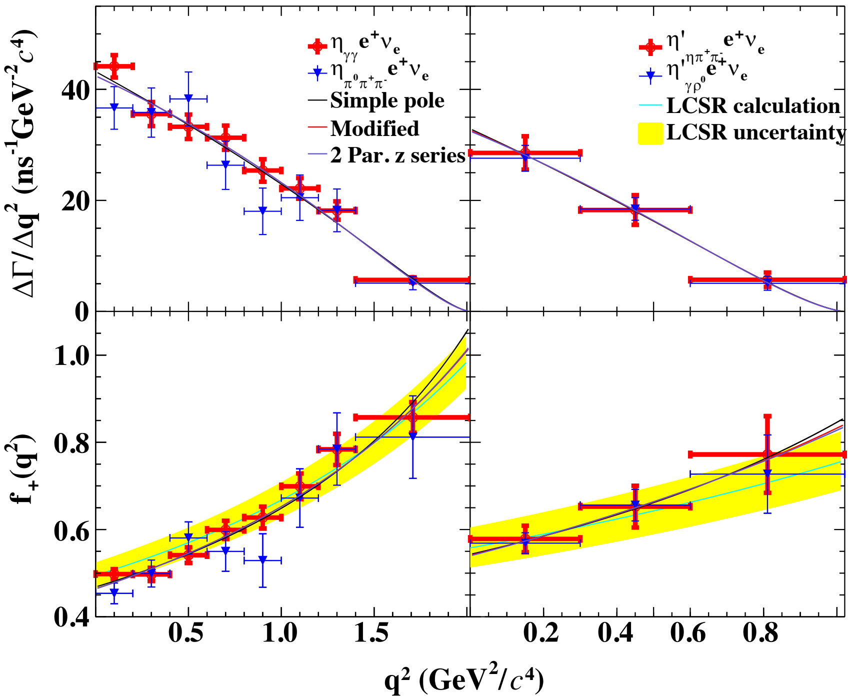
$f_+^{\eta}(0)$

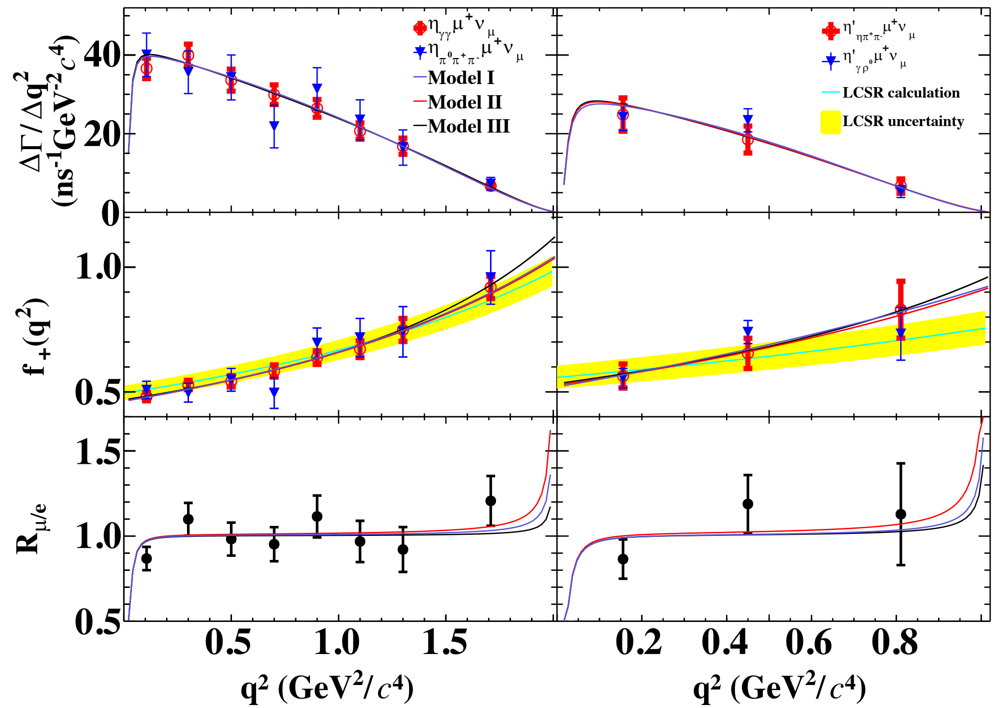


large deviation from LQCD results

$f_+^{\eta'}(0)$

Energy-dependent form factors





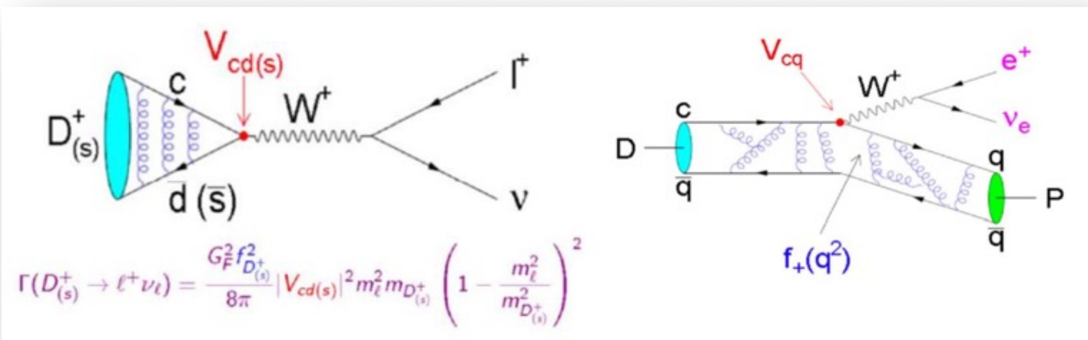
data: BESIII, arXiv:2306.05194, arXiv:2307.12852
LCSR: JHEP11, 138 (2015)

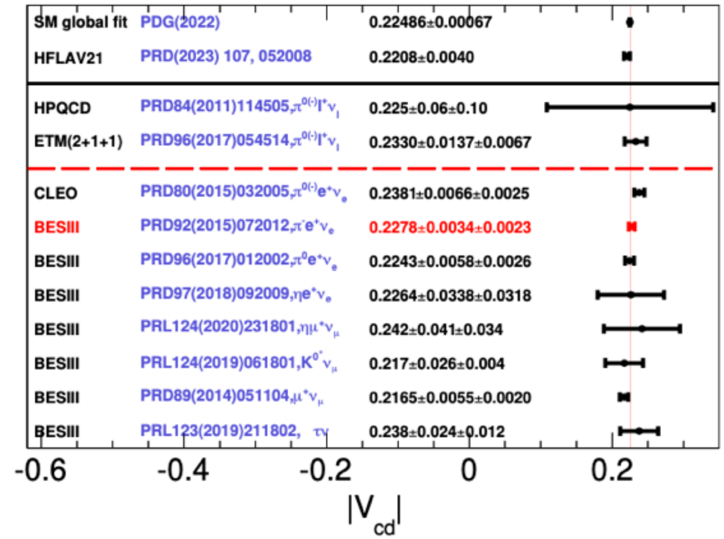
More form factors

Chain	Ref.	$L/E_{\rm cm}$ ($\rm fb^{-1}$/GeV)	BF(%)	FF
$D^0 \to K^{*-}e^+\nu_e$	PRD99,0111003	2.93/3.773	$1.434 \pm 0.029 \pm 0.032$	$r_V = 1.46 \pm 0.07 \pm 0.02$ $r_2 = 0.67 \pm 0.06 \pm 0.01$
$D^+ \to \bar{K}^{*0}e^+\nu_e$	PRD94,032001	2.93/3.773	$3.77 \pm 0.03 \pm 0.08$	$r_V = 1.411 \pm 0.058 \pm 0.007$ $r_2 = 0.788 \pm 0.042 \pm 0.008$
$D \to \rho e^+\nu_e$	PRL122,062001	2.93/3.773	D^0: $0.1445 \pm 0.0058 \pm 0.0039$ D^+: $0.1860 \pm 0.0070 \pm 0.0061$	$r_V = 1.695 \pm 0.083 \pm 0.051$ $r_2 = 0.845 \pm 0.056 \pm 0.039$
$D^0 \to \rho^-\mu^+\nu_\mu$	PRD104,L091103	2.93/3.773	$0.135 \pm 0.009 \pm 0.009$	–
$D^+ \to \omega e^+\nu_e$	PRD92,071101	2.93/3.773	$0.163 \pm 0.011 \pm 0.008$	$r_V = 1.24 \pm 0.09 \pm 0.06$ $r_2 = 1.06 \pm 0.15 \pm 0.05$
$D^+ \to \omega\mu^+\nu_\mu$	PRD101,072005	2.93/3.773	$0.177 \pm 0.018 \pm 0.011$	–
$D_s^+ \to K^{*0}e^+\nu_e$	PRL122,061801	3.19/4.178	$0.237 \pm 0.026 \pm 0.020$	$r_V = 1.67 \pm 0.34 \pm 0.16$ $r_2 = 0.77 \pm 0.28 \pm 0.07$
$D_s^+ \to \phi e^+\nu_e$	PRD97,012006	0.482/4.009	$2.26 \pm 0.45 \pm 0.09$	–
$D_s^+ \to \phi\mu^+\nu_\mu$	arXiv:2307.03024	7.33/4.128-4.226	$2.25 \pm 0.09 \pm 0.07$	$r_V = 1.58 \pm 0.17 \pm 0.02$ $r_2 = 0.71 \pm 0.14 \pm 0.02$

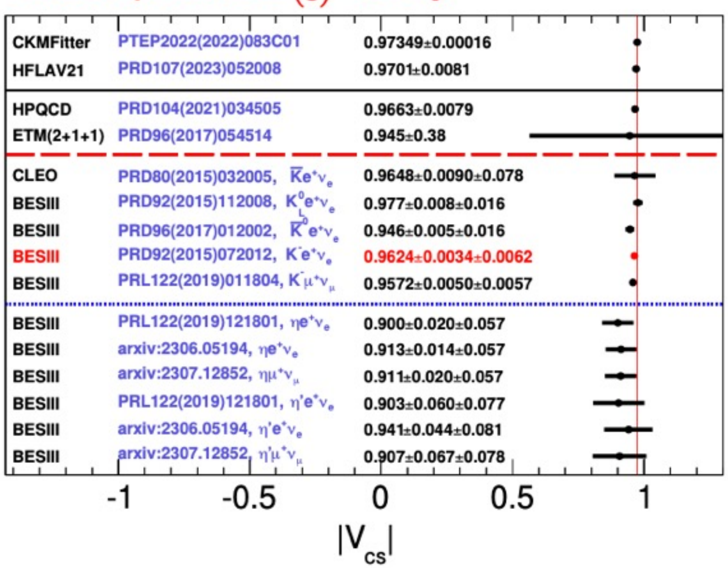
- **Precisions will be improved much with future 20/fb $\psi(3770)$ data**
- **LQCD calculations are desired.**

Measurement of |Vcs| and |Vcd|

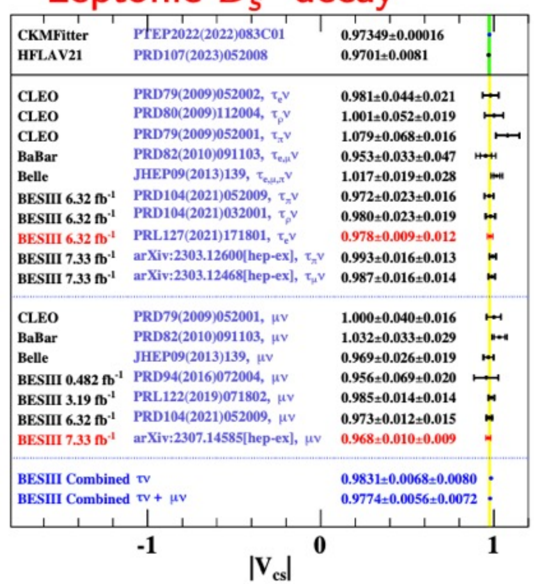




Semileptonic $D_{(s)}$ decay



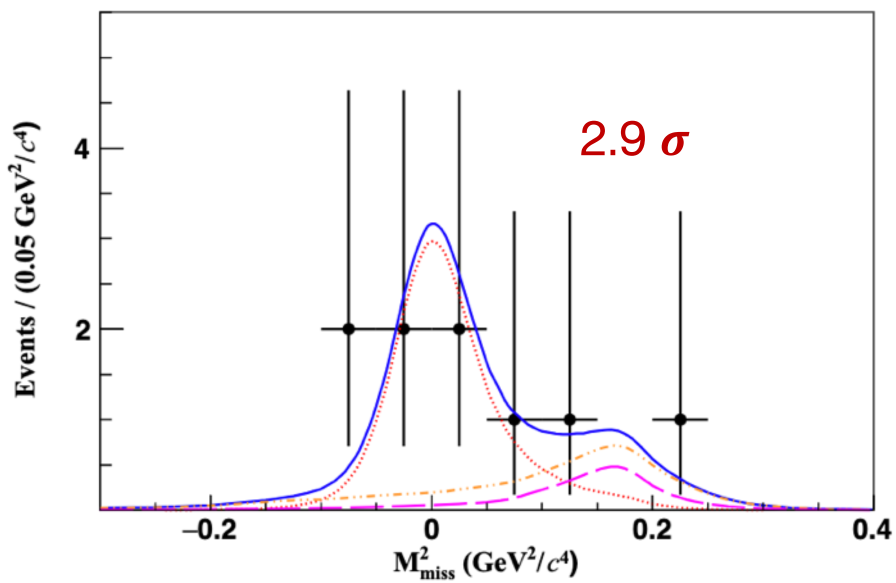
Leptonic D_s^+ decay

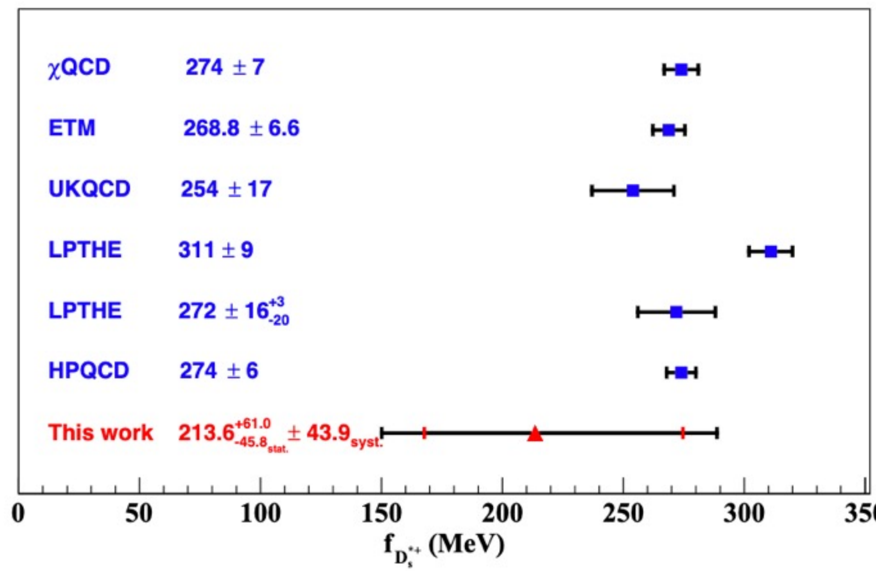


- Great precision improvement due to LQCD form factors
- No sign of conflicts between direct measurement and indirect fit

Study on $D_s^{*+} \to e^+\nu$

arXiv:2304.12159





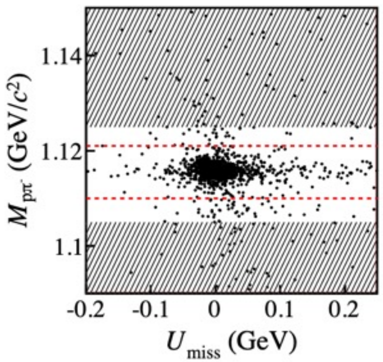
- Branching fraction is determined to be $(2.1^{+1.2}_{-0.9\,\text{stat.}} \pm 0.2_{\text{syst.}}) \times 10^{-5}$

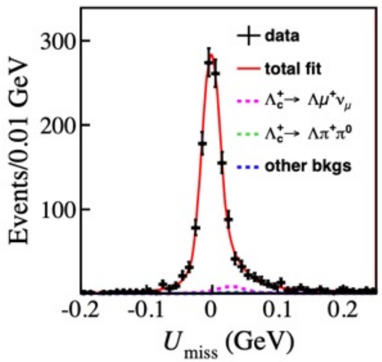
an avenue to study the weak decays of vector charmed mesons in experiment

Recent results on Λ_c^+ leptonic decays

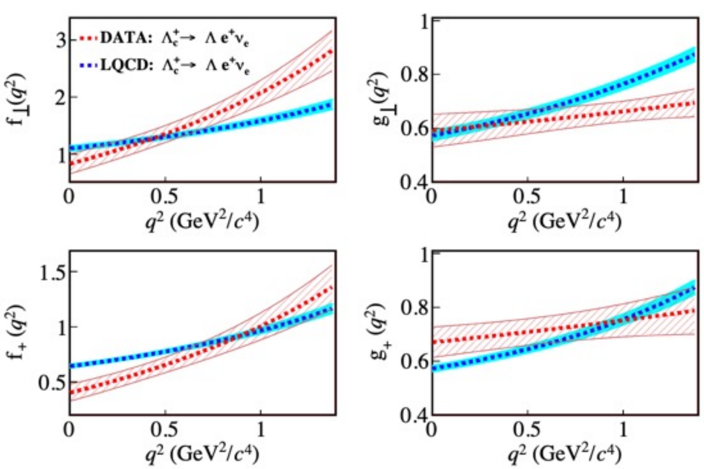
Determination of form factors of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

PRL129, 231803 (2022)





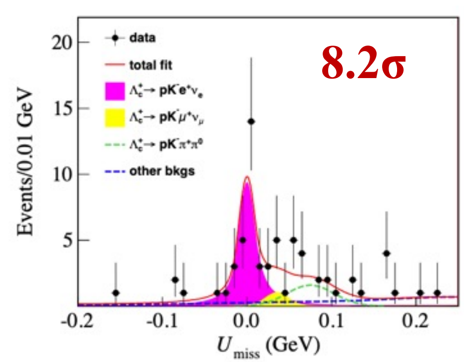
$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$

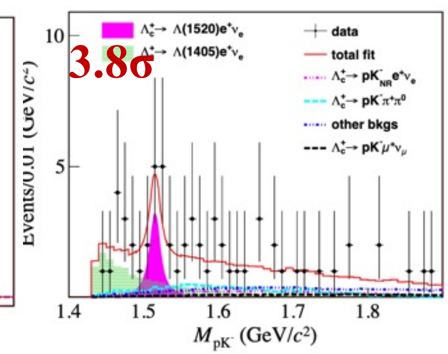


First direct comparisons on the differential decay rates and form factors with LQCD calculations [PRL118, 082001 (2017)]

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

PRD106, 112010 (2022)





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

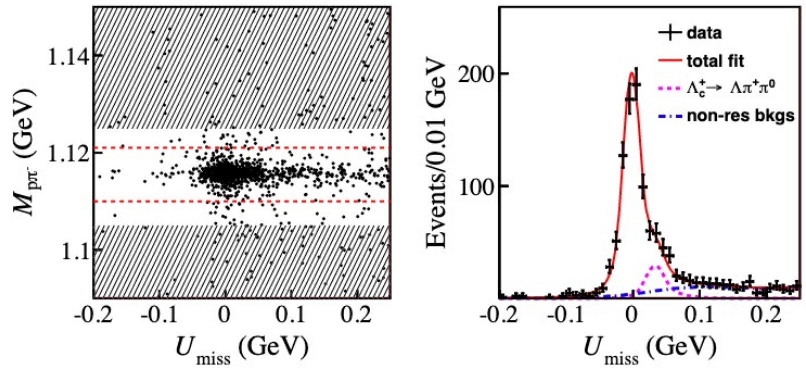
$B(\Lambda_c^+ \to \Lambda(1405) e^+ \nu) = (1.69 \pm 0.76 \pm 0.16) \times 10^{-3}$

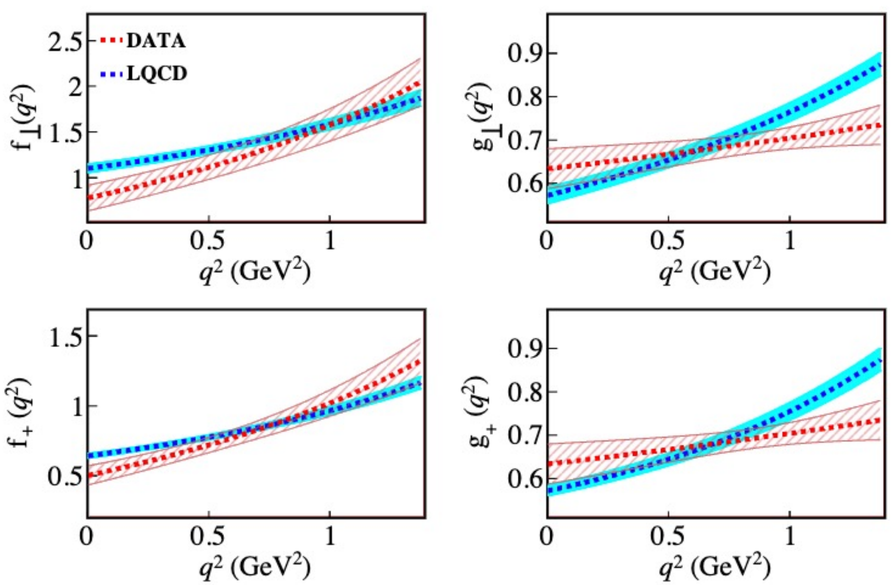
$B(\Lambda_c^+ \to \Lambda(1520) e^+ \nu) = (0.99 \pm 0.51 \pm 0.10) \times 10^{-3}$

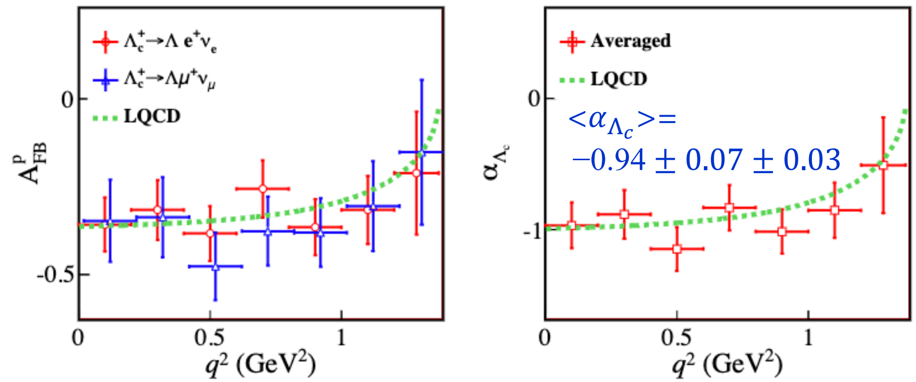
- Second leptonic decay of Λ_c^+ is observed!
- Good channel to study Λ excited states, such as Λ(1405) and Λ(1520)

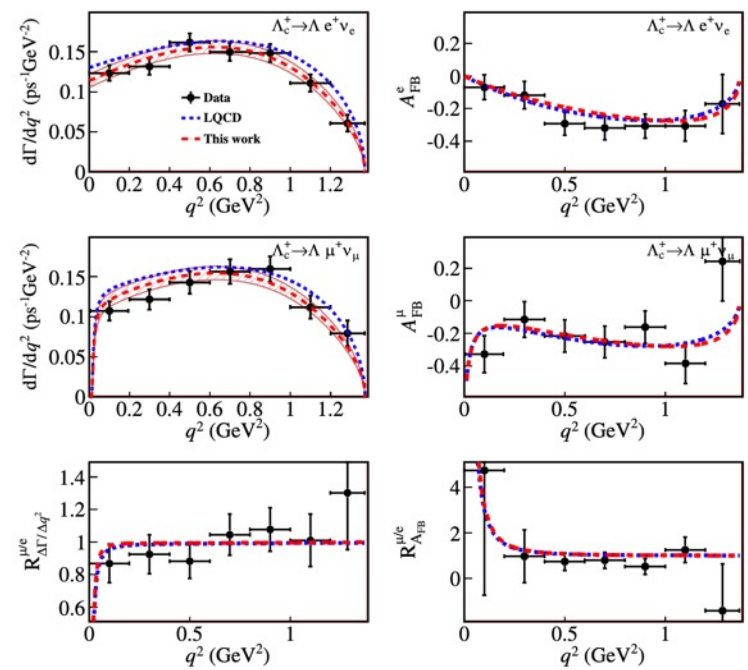
Combined form factor fits to $\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$ and $\Lambda e^+\nu_e$

PRD108, L031105 (2023)



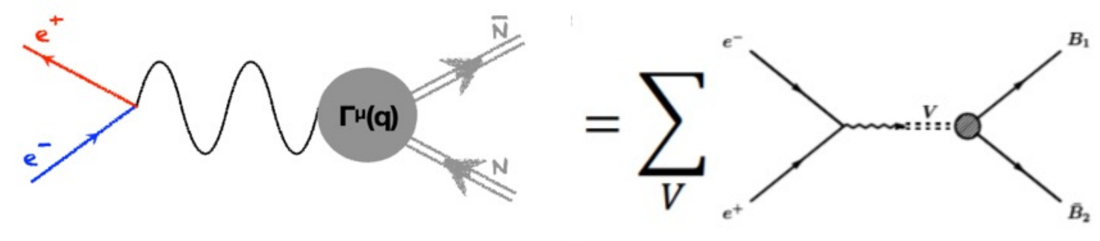


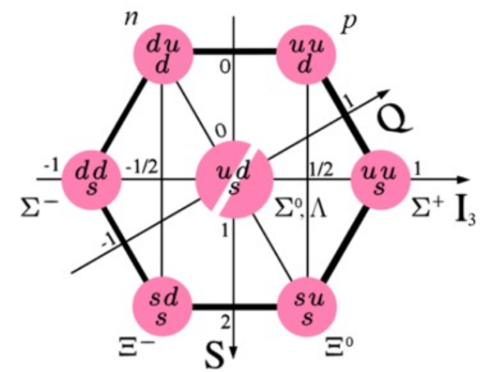


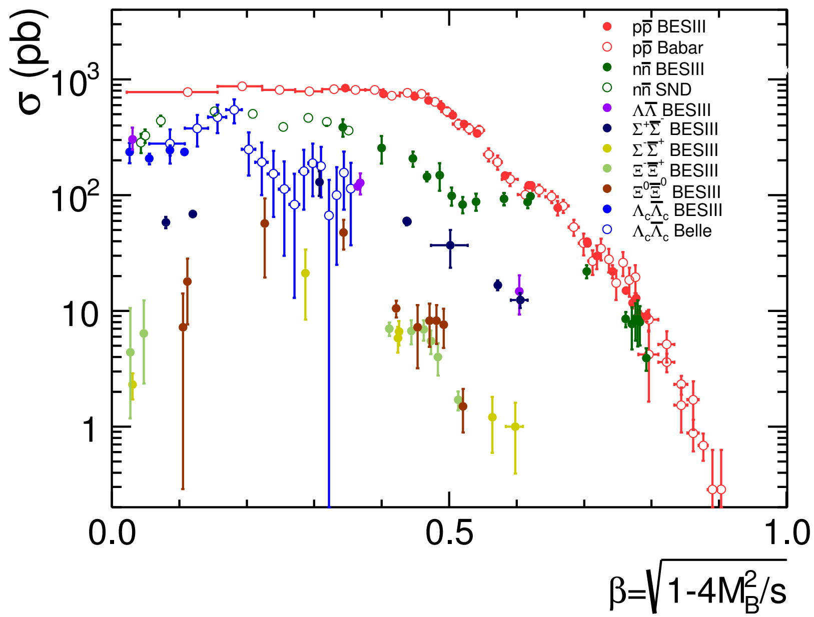


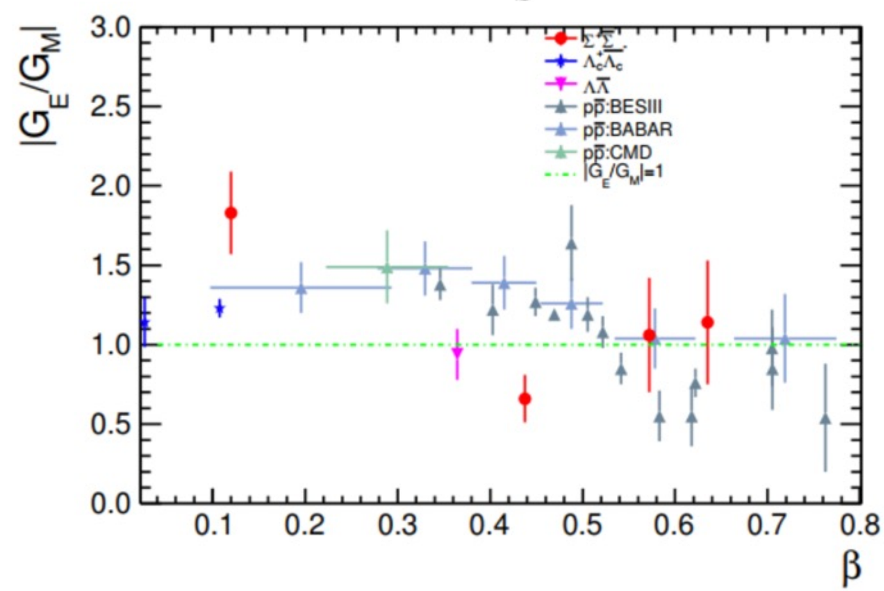
LQCD results from
S. Meinel, PRL118, 082001 (2017)

Baryon pair production









- **Abnormal threshold effects** observed in various baryon pair production: $p\bar{p}$, $\Lambda\bar{\Lambda}$, $\Lambda_c^+\bar{\Lambda}_c^-$ …
- $|G_E/G_M|$ ratio significantly larger than 1 at low beta for p, Λ_c^+, Σ^+, indicating large D-wave near threshold.

Hyperon physics at BESIII

10 billion J/psi events collected

- Large rates in J/ψ decays
- Quantum entangled pair productions
- Background free, high efficiency

Hai-Bo Li, arXiv:1612.01775
A. Adlarson, A. Kupsc, arXiv:1908.03102

a hyperon factory!

Decay mode	$\mathcal{B}(\times 10^{-3})$	$N_B\ (\times 10^6)$
$J/\psi \to \Lambda\bar{\Lambda}$	1.61 ± 0.15	16.1 ± 1.5
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.29 ± 0.09	12.9 ± 0.9
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.50 ± 0.24	15.0 ± 2.4
$J/\psi \to \Sigma(1385)^-\bar{\Sigma}^+$ (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
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.86 ± 0.11	8.6 ± 1.0
$J/\psi \to \Xi(1530)^0\bar{\Xi}^0$	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

CPV in SM is small：			# events	Experiments
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 ?

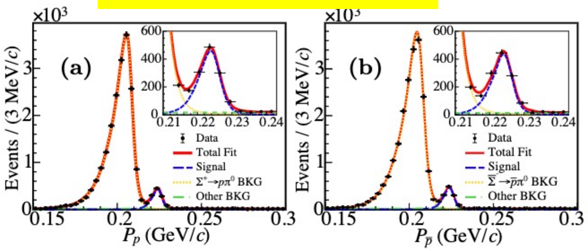
1980

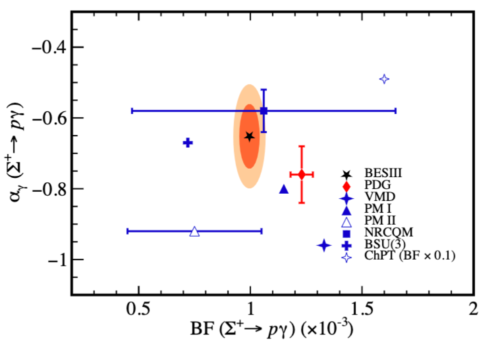
2008

Study on hyperon rare decays

$\Sigma^+ \to \gamma p$ from $J/\psi \to \Sigma^+\bar{\Sigma}^-$

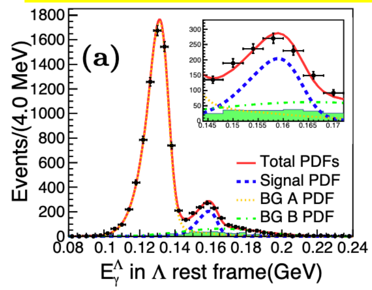
PRL 130, 211901 (2023)

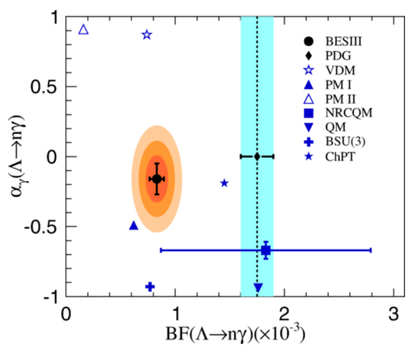




$\Lambda \to \gamma n$ in $J/\psi \to \Lambda\bar{\Lambda}$

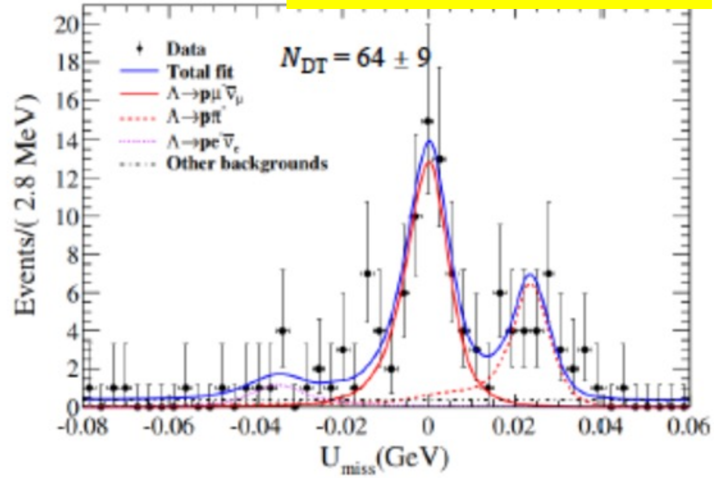
PRL129, 212002 (2022)



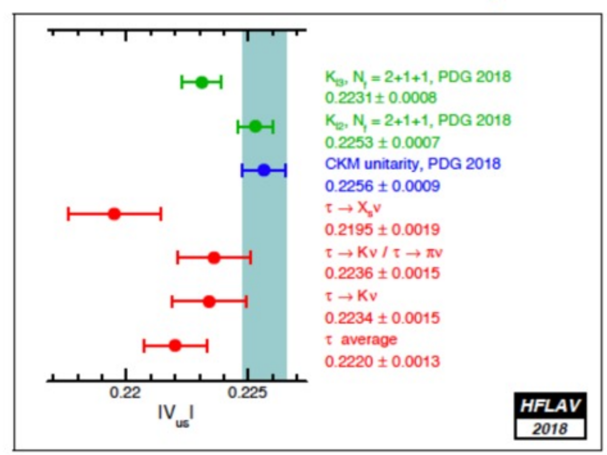


$\Lambda \to p\mu^-\nu$ in $J/\psi \to \Lambda\bar{\Lambda}$

PRL 127, 121802 (2023)

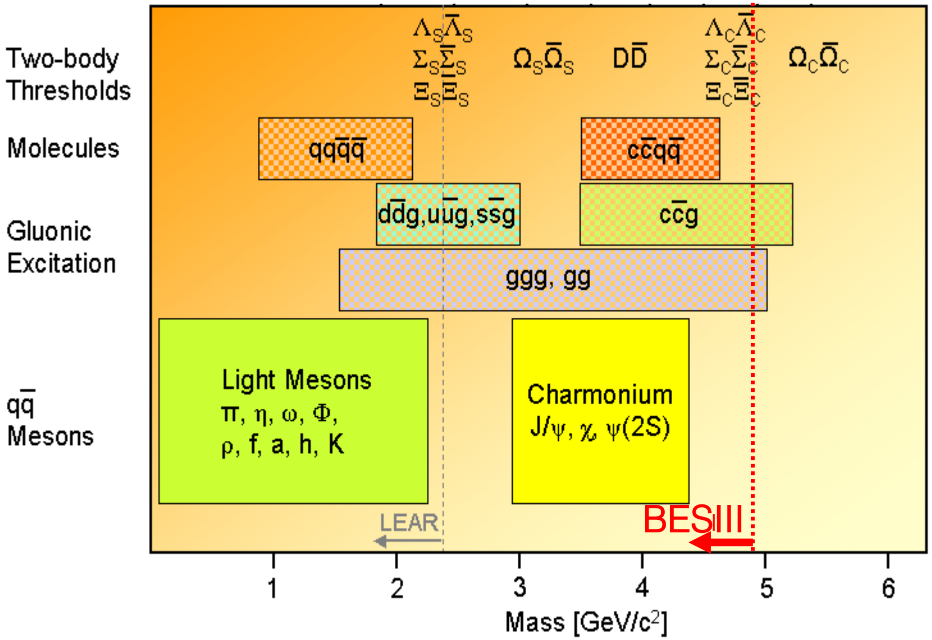


inconsistent |Vus| measurement



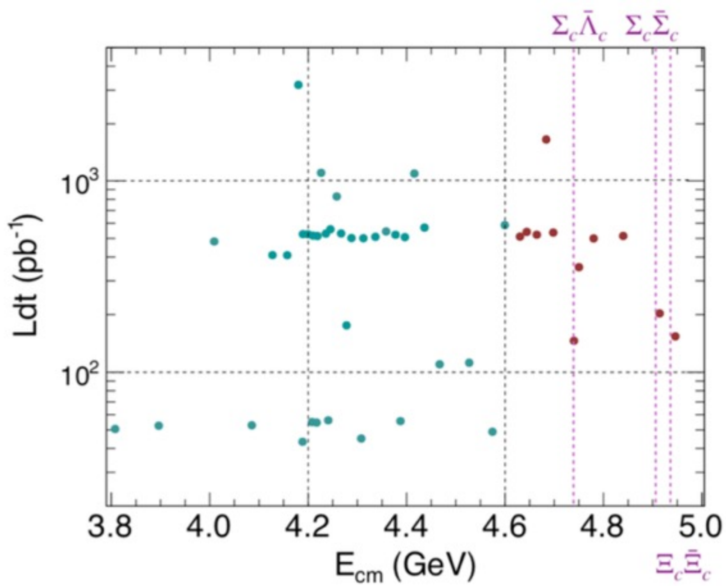
Hadron Spectroscopy

Hadron Landscape



Hadron-physics challenges:

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

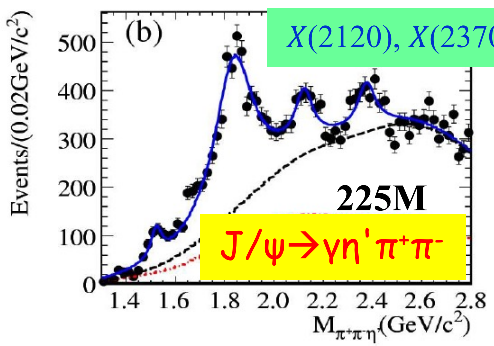


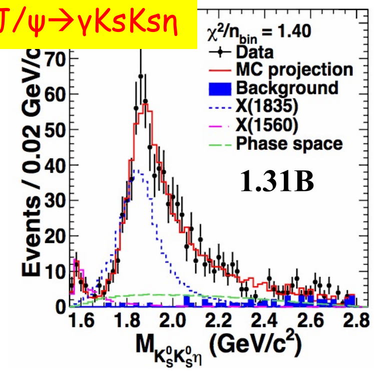
XYZ studies: about 23 /fb data above 3.8 GeV

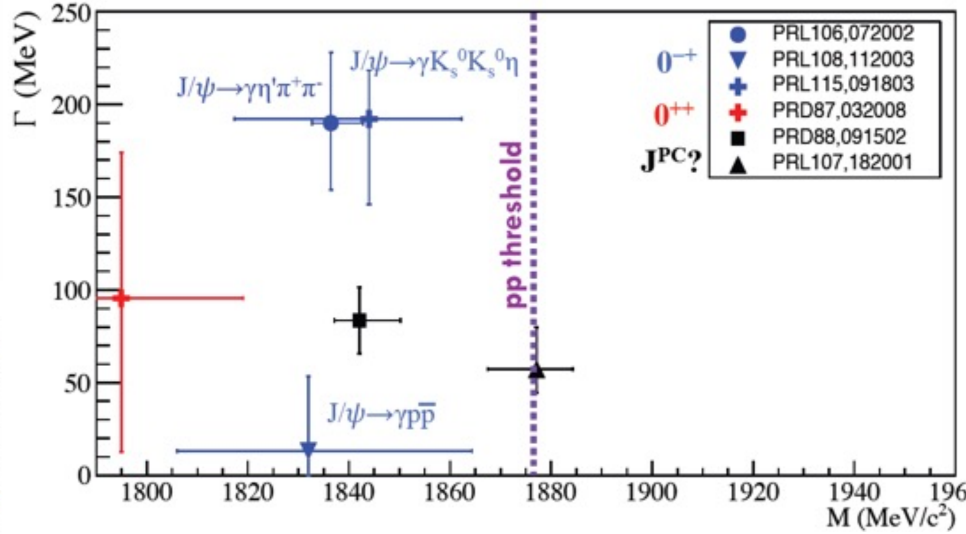
At BESIII, two golden measures to study hadron spectroscopy, *esp*., to search for exotics

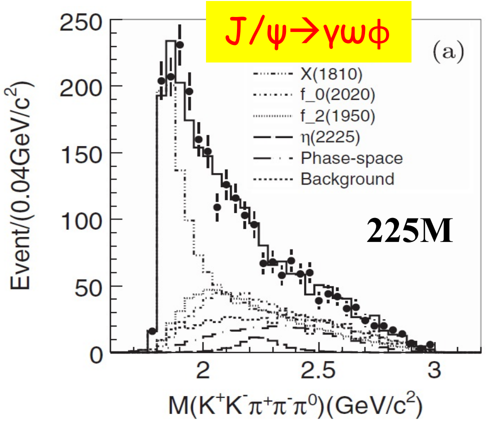
- Light hadrons: charmonium radiative decays (act as spin filter) (**10 B J/ψ and 3 B $\psi(2S)$**)
- Heavy hadrons: direct production, radiative and hadronic transitions (**data above 3.8 GeV**)

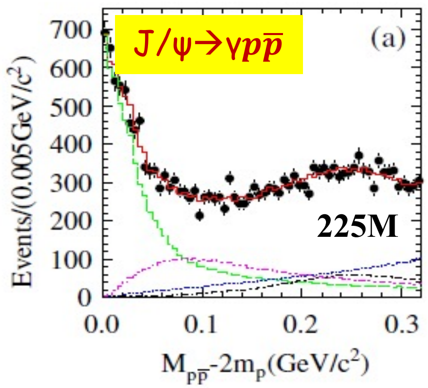
$X(p\bar{p})$/X(18??) from J/ψ radiative decays





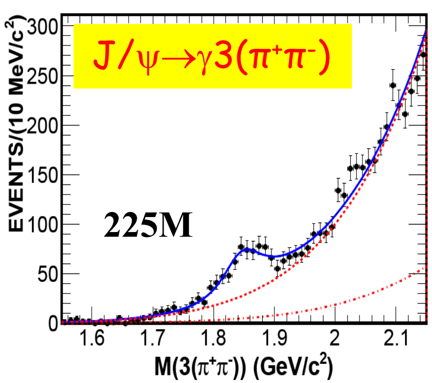


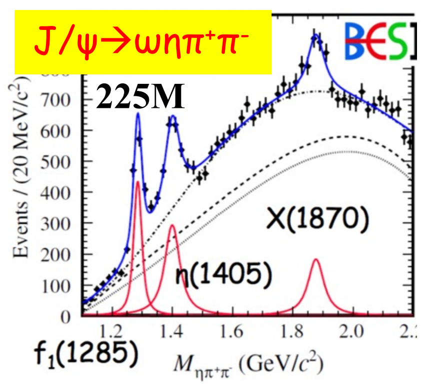


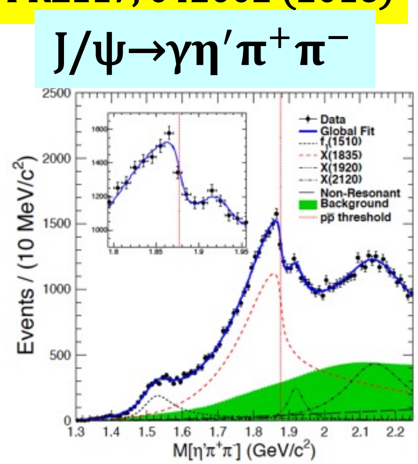


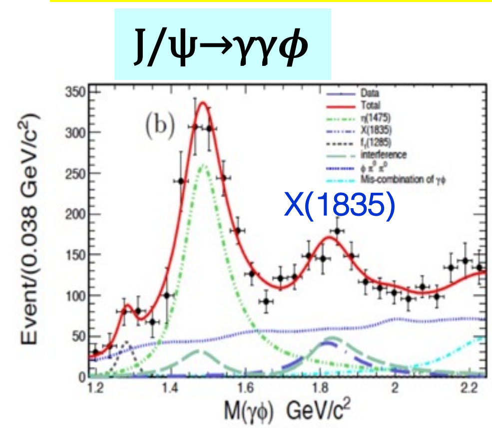
PRL117, 042002 (2016)

PRD97, 051101(R)(2018)



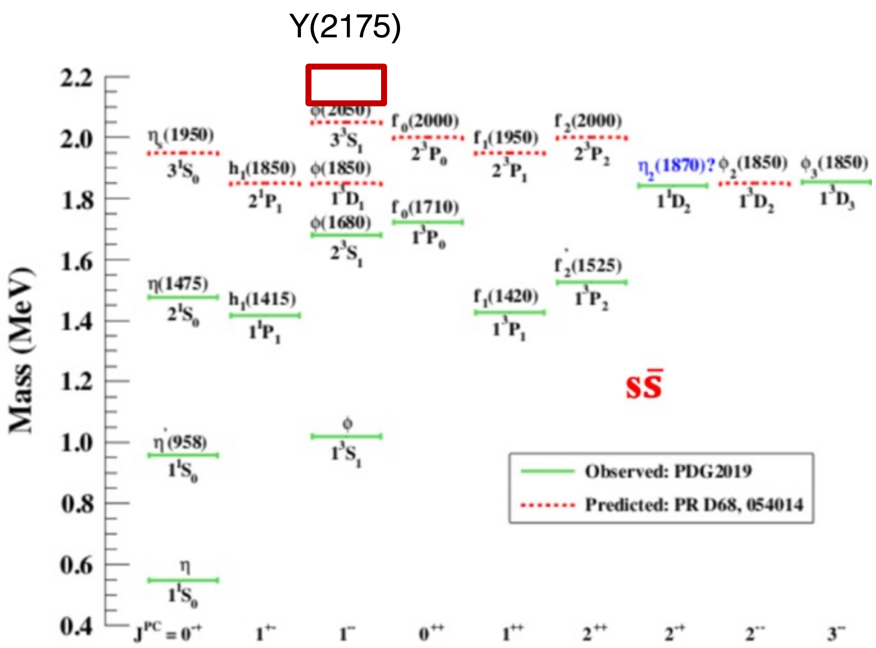


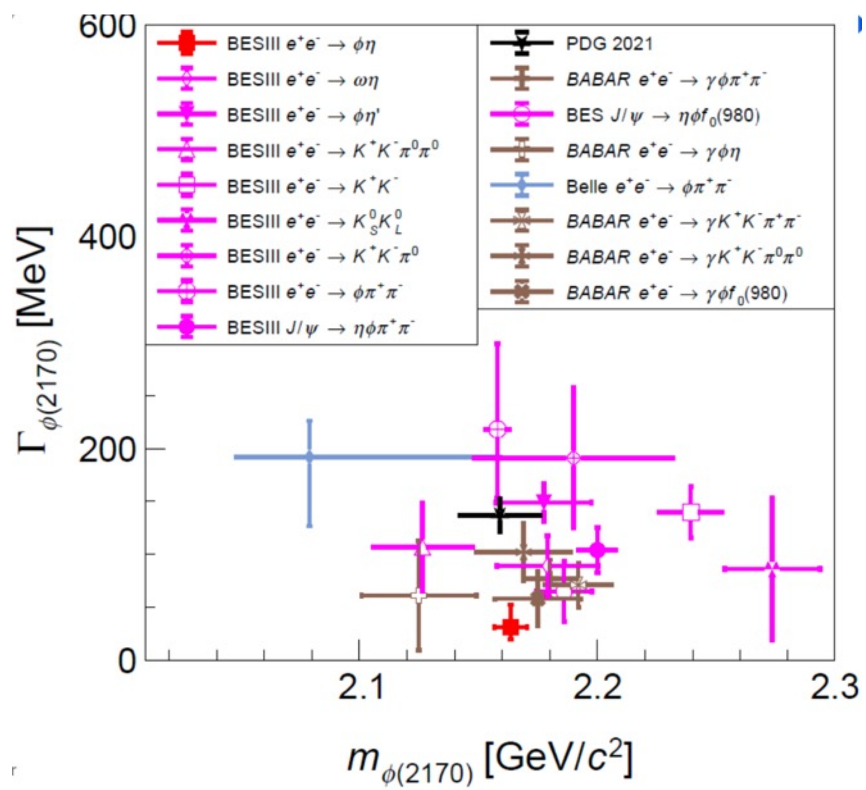




Are they the same state? It is crucial to understand their connections.

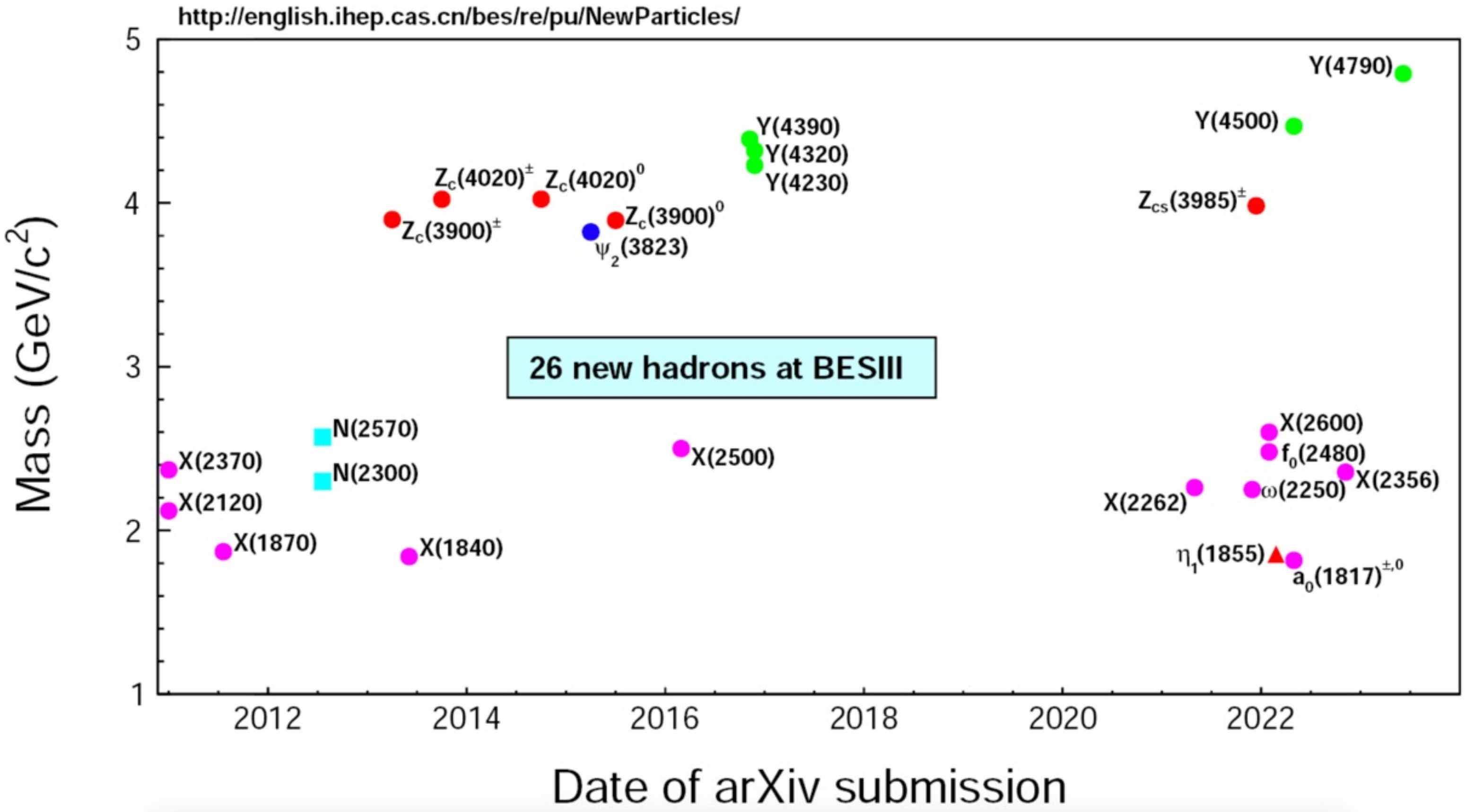
Rediscovery of Y(2175)/ϕ(2170)



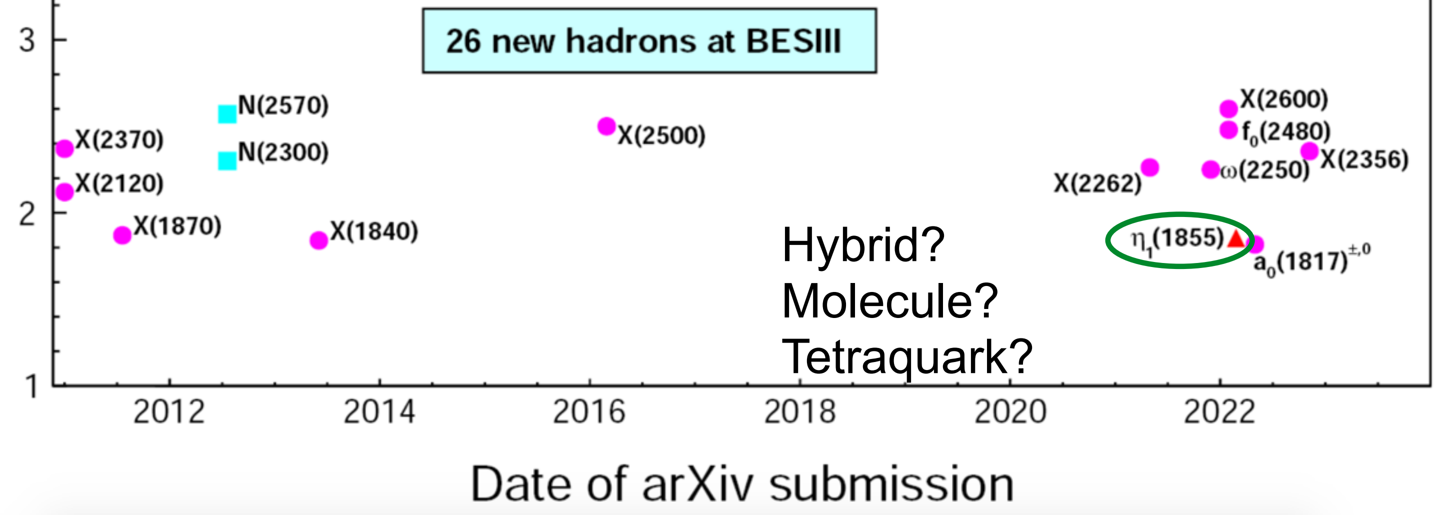


- **Theorists explain ϕ(2170) as**
  - ✓ $s\bar{s}g$ hybrid
  - ✓ 2^3D_1 or 3^3S_1 $s\bar{s}$
  - ✓ tetraquark
  - ✓ Molecular state $\Lambda\bar{\Lambda}$
  - ✓ $\phi f_0(980)$ resonance with FSI
  - ✓ Three body system ϕKK

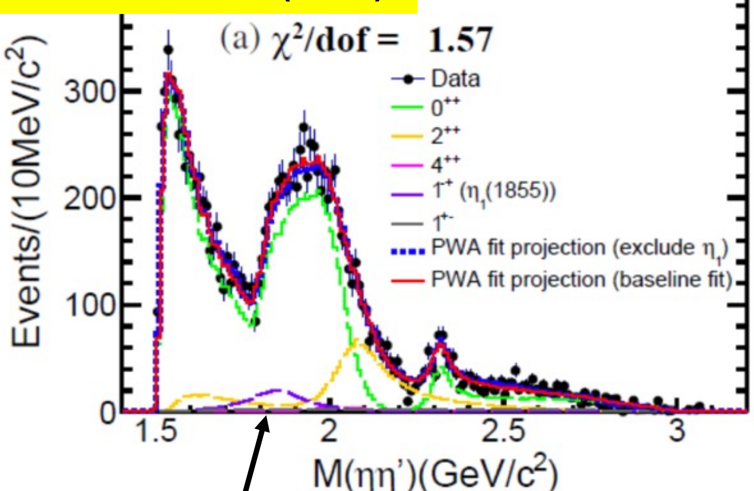
26 New Hadrons Discovered at BESIII



BESIII



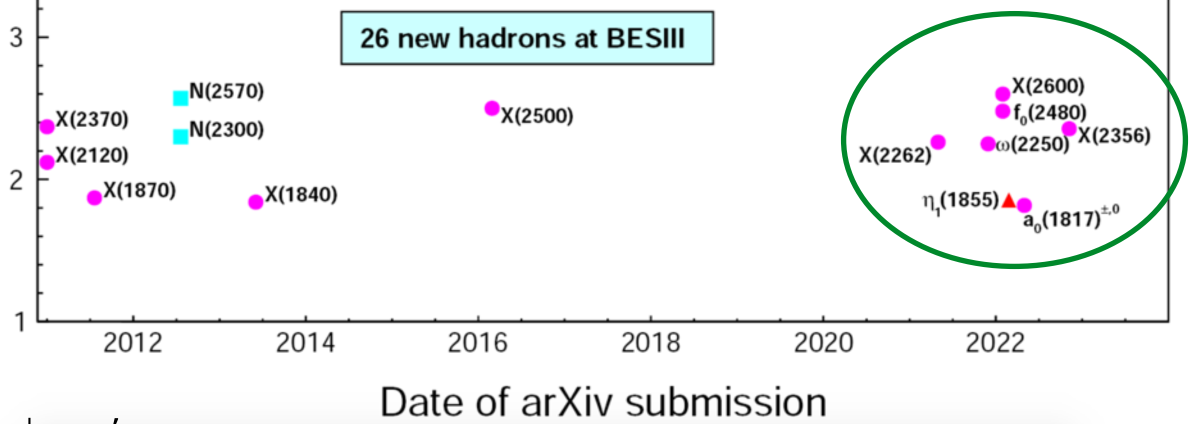
PRL129, 192002 (2022)
PRD106, 072012 (2022)



$\boldsymbol{\eta_1(1855)(1^{-+})}$

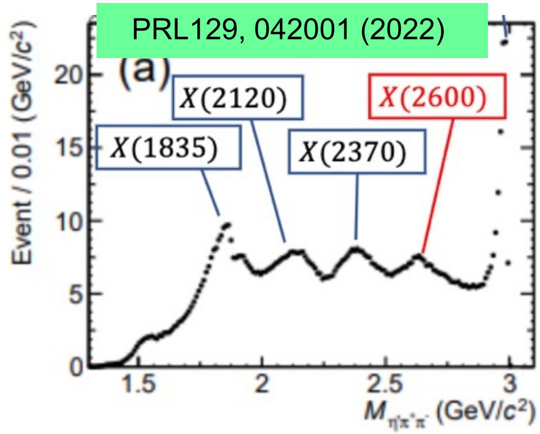
Decay mode	Resonance	M (MeV/c^2)	Γ (MeV)	$M_{\rm PDG}$ (MeV/c^2)	$\Gamma_{\rm PDG}$ (MeV)	B.F. ($\times 10^{-5}$)	Sig.
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_0(1500)$	1506	112	1506	112	$1.81\pm0.11^{+0.19}_{-0.13}$	$\gg30\sigma$
	$f_0(1810)$	1795	95	1795	95	$0.11\pm0.01^{+0.04}_{-0.03}$	11.1σ
	$f_0(2020)$	$2010\pm6^{+6}_{-4}$	$203\pm9^{+13}_{-11}$	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

BESIII



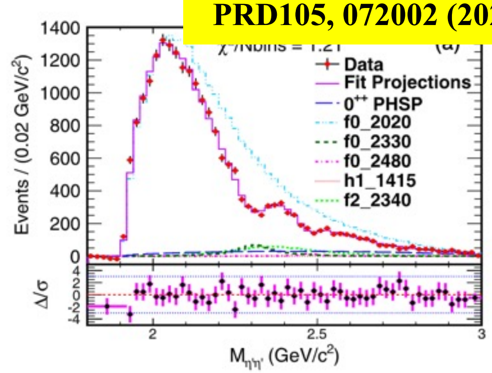
$X(2600)$ in $J/\psi \to \gamma\pi^+\pi^-\eta'$

PRL129, 042001 (2022)



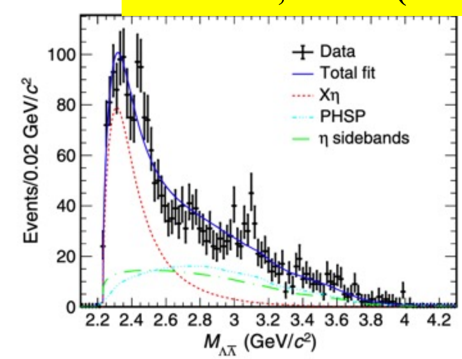
$f_0(2480)$ in $J/\psi \to \gamma\eta'\eta'$

PRD105, 072002 (2022)



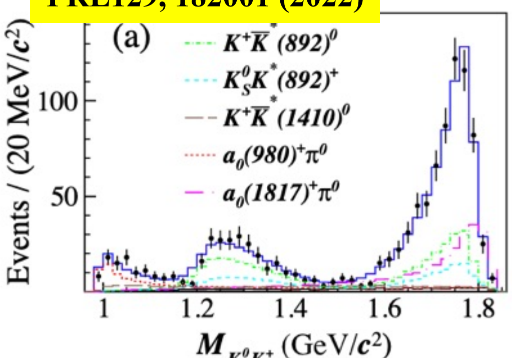
$X(2356) \to \Lambda\bar{\Lambda}$ in $e^+e^- \to \eta\Lambda\bar{\Lambda}$

PRD 107, 112001 (2023)



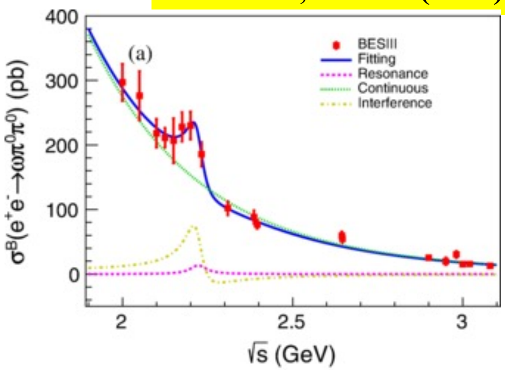
$a_0(1817)$ in $D_s^+ \to K_S K^+\pi^0$

PRL129, 182001 (2022)



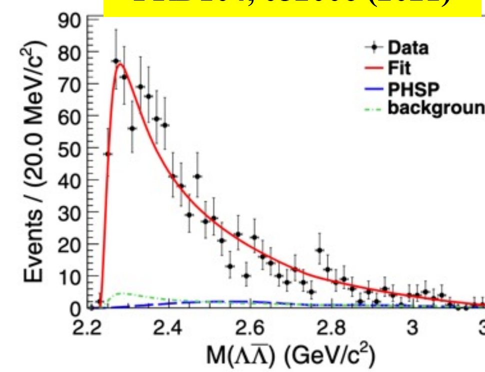
$\omega(2250)$ in $e^+e^- \to \omega\pi^0\pi^0$

PRD 105, 032005 (2022)



$X(2262) \to \Lambda\bar{\Lambda}$ in $e^+e^- \to \phi\Lambda\bar{\Lambda}$

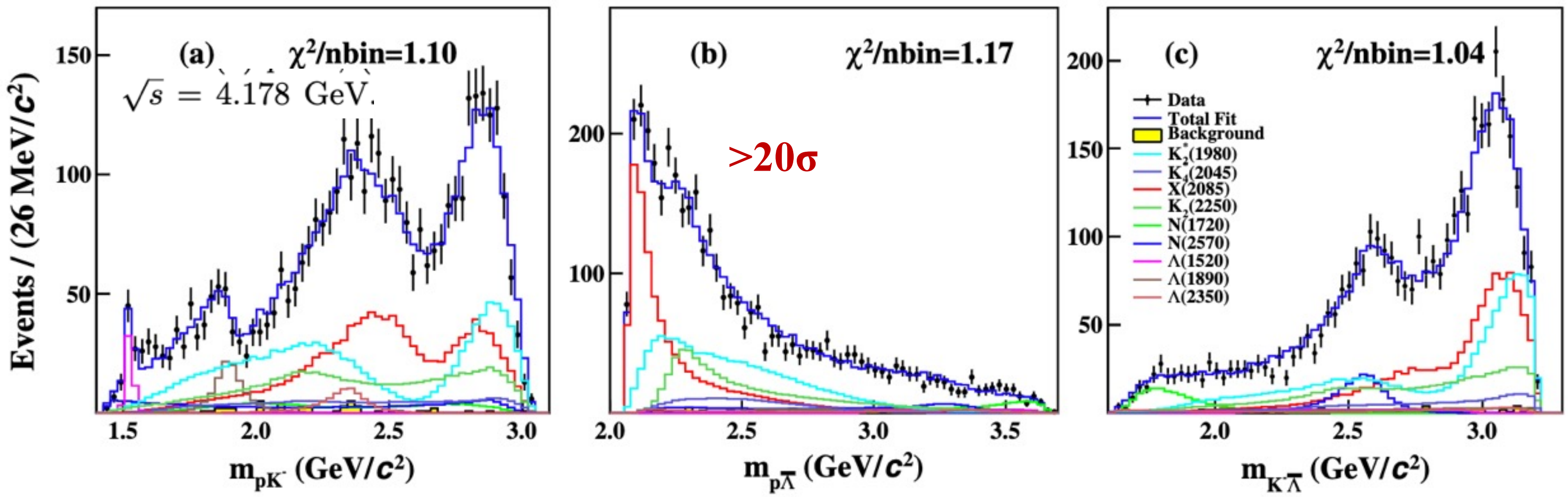
PRD104, 052006 (2021)



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

arXiv:2303.01989

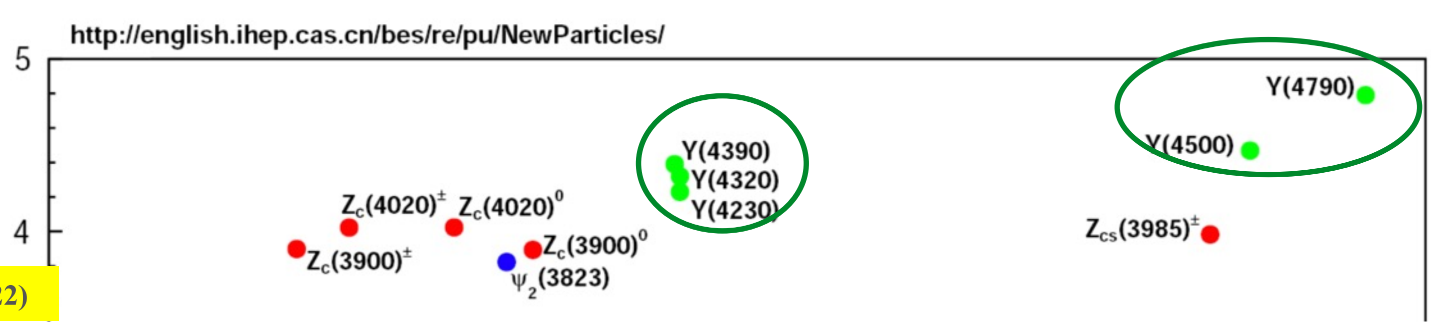
8.35 fb^{-1} data at 4.008, 4.178, 4.226, 4.258, 4.416, and 4.682 GeV



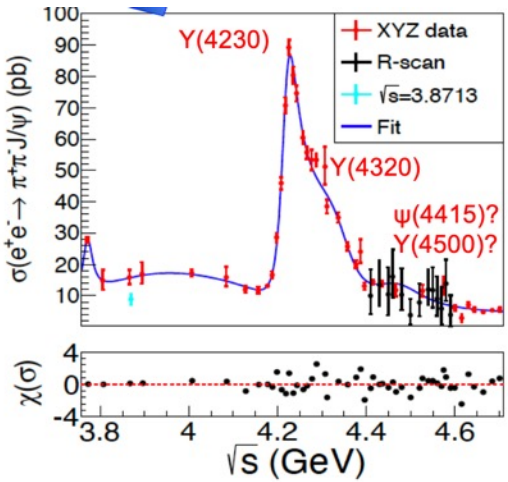
$\sqrt{s}$	$\mathcal{L}_{\mathrm{int}}$	Year	M_{pole}	Γ_{pole}
4.008	482.0 ± 4.7	2011	2085 ± 14	50 ± 16
4.178	3189.0 ± 31.9	2016	2085 ± 6	62 ± 10
4.226	1100.9 ± 7.0	2013	2088 ± 10	68 ± 12
4.258	828.4 ± 5.5	2013	2083 ± 11	48 ± 10
4.416	1090.7 ± 7.2	2014	2088 ± 13	56 ± 12
4.682	1669.3 ± 9.0	2020	2092 ± 10	54 ± 10
Average	—	—	2086 ± 4	56 ± 5

- $p\bar{\Lambda}$ 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

BESIII



PRD106, 072001 (2022)

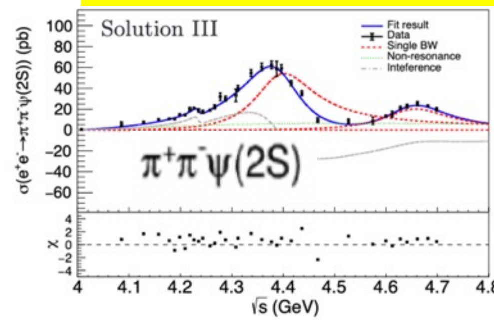


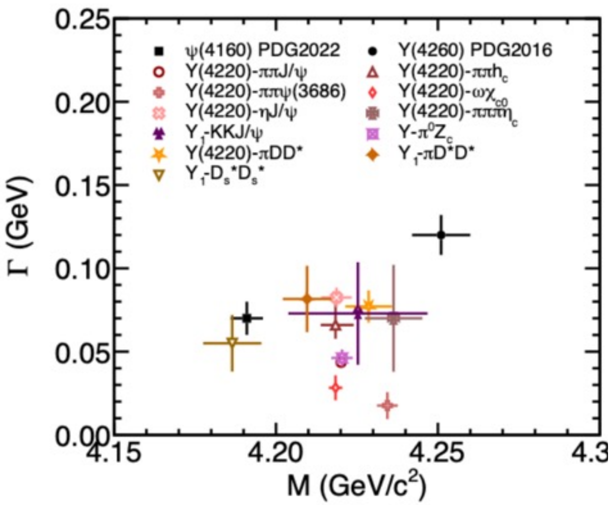
Y(4260) ➔ Y(4230) & Y(4320)

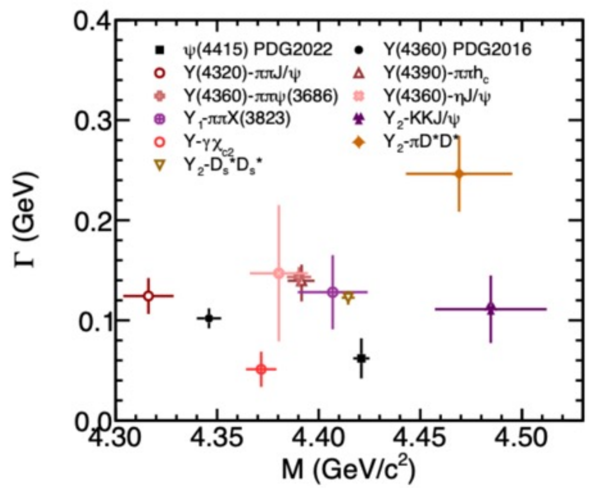
$$M_{Y(4230)} = 4221.4 \pm 1.5 \pm 2.0\ \mathrm{MeV}/c^2$$
$$\Gamma_{Y(4230)} = 41.8 \pm 2.9 \pm 2.7\mathrm{MeV}$$

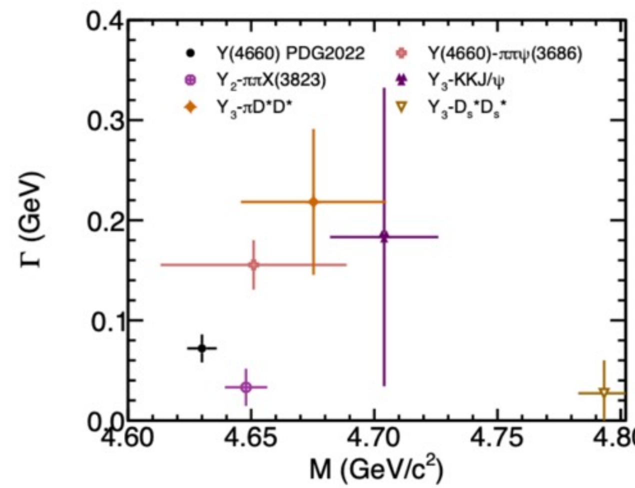
$$M_{Y(4320)} = 4298 \pm 12 \pm 26\ \mathrm{MeV}/c^2$$
$$\Gamma_{Y(4320)} = 127 \pm 17 \pm 10\ \mathrm{MeV}$$

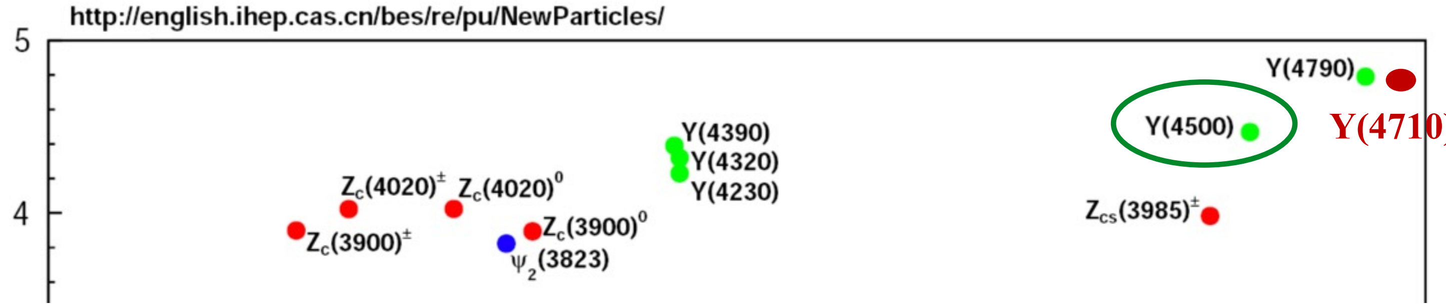
PRD 104, 052012 (2021)







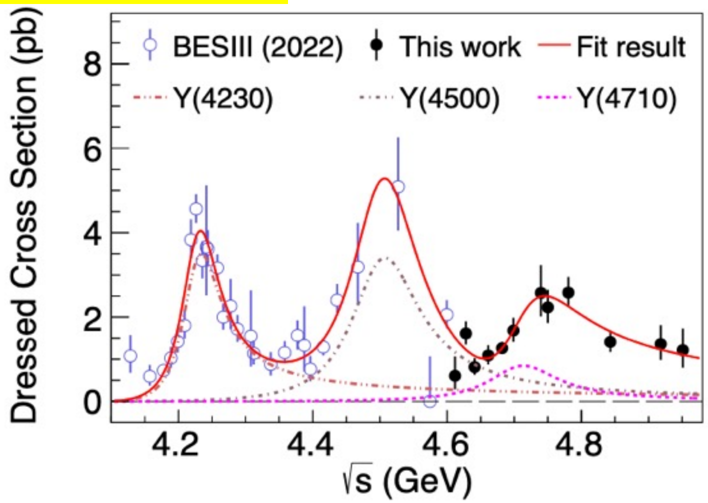


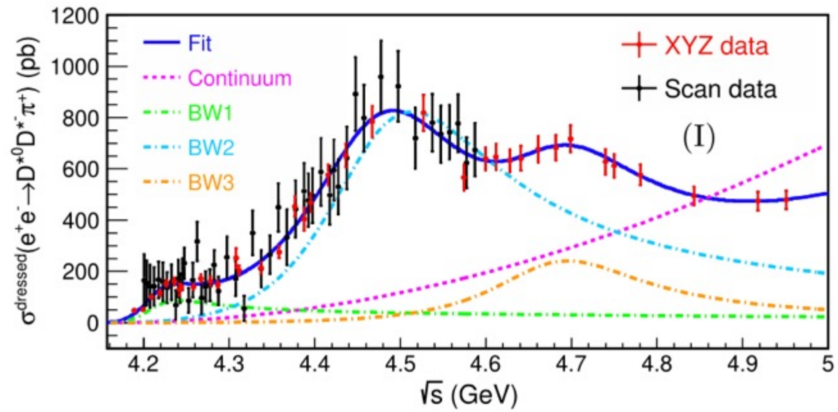


CPC 46, 111002 (2022)
arXiv:2308.15362

observation of the Y(4710)

PRL130, 121901 (2023)





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

Y(4710) mass: $4708^{+17}_{-15} \pm 21$ MeV$/c^2$
Y(4710) width: $126^{+27}_{-23} \pm 30$ MeV

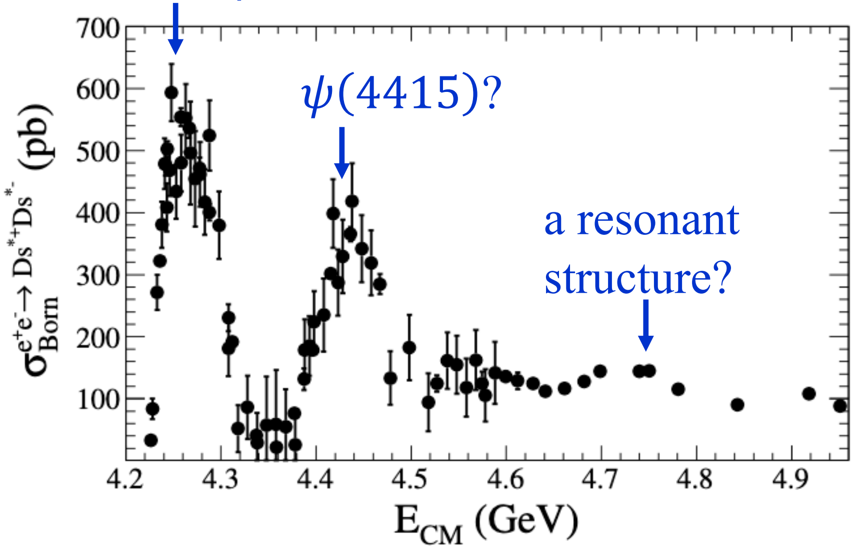
$m_1 = 4209.6 \pm 4.7 \pm 5.9$ MeV$/c^2$, $\Gamma_1 = 81.6 \pm 17.8 \pm 9.0$ MeV; → Y(4230)

$m_2 = 4469.1 \pm 26.2 \pm 3.6$ MeV$/c^2$, $\Gamma_2 = 246.3 \pm 36.7 \pm 9.4$ MeV; → Y(4500)

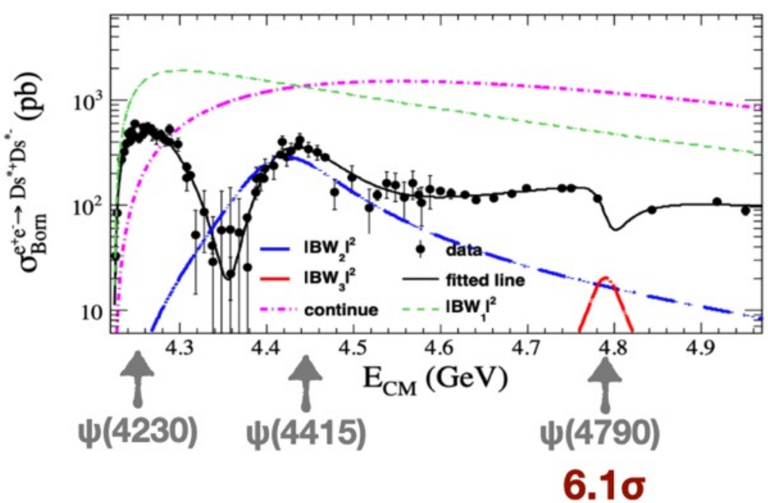
$m_3 = 4675.3 \pm 29.5 \pm 3.5$ MeV$/c^2$, $\Gamma_3 = 218.3 \pm 72.9 \pm 9.3$ MeV. → Y(4660)

Cross sections of $e^+e^- \to D_s^{*+}D_s^{*-}$

arXiv:2305.10789



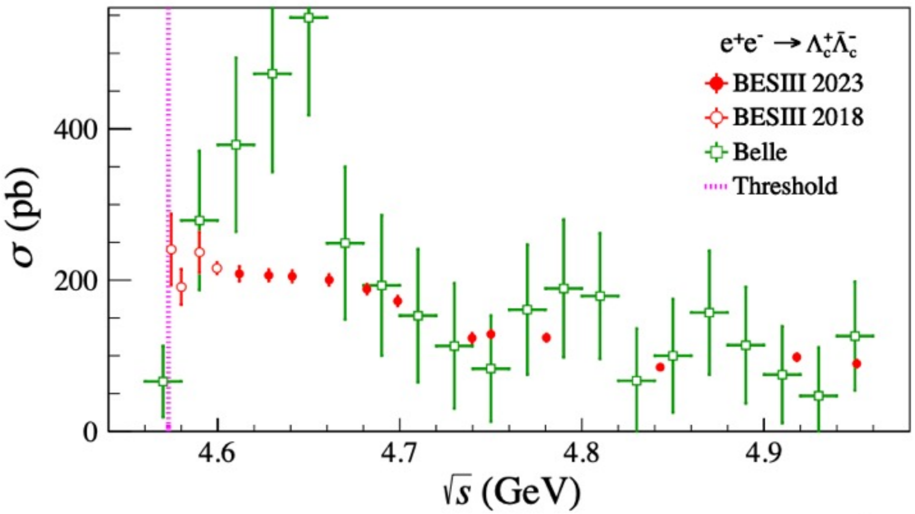
	Result 1	Result 2	Result 3
M_1 (MeV/c^2)	4186.5±9.0	4193.8±7.5	4195.3±7.5
Γ_1 (MeV)	55±17	61.2±9.0	61.8±9.0
M_2 (MeV/c^2)	4414.5±3.2	4412.8±3.2	4411.0±3.2
Γ_2 (MeV)	122.6±7.0	120.3±7.0	120.0±7.0
M_3 (MeV/c^2)	4793.3±7.5	4789.8±9.0	4786±10
Γ_3 (MeV)	27.1±7.0	41±39	60±35

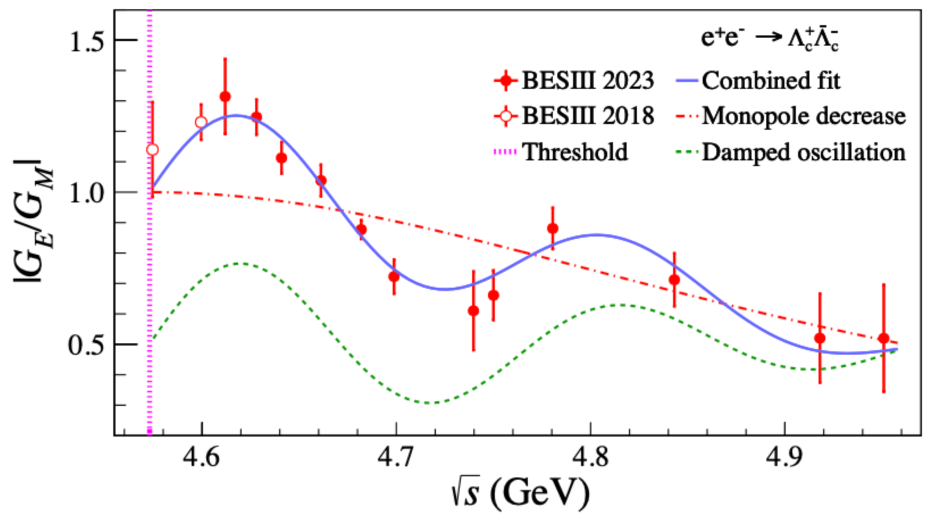


Y(4790): the heaviest charmoniumlike state!

Cross sections of $e^+e^- \to \Lambda_c^+\Lambda_c^-$

arXiv:2307.07316

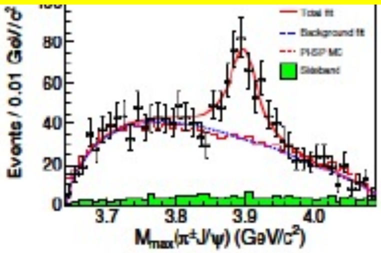




- Negate the $Y(4630)$ in decaying into $\Lambda_c^+\Lambda_c^-$ reported by BELLE
- Energy-dependence of $|G_E/G_M|$ reveals an oscillation feature, which may imply a non-trivial structure of the lightest charmed baryon.

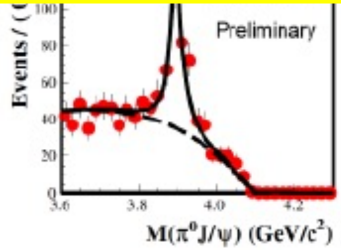
The Z_c family at BESIII

Zc(3900)$^+$
PRL 110, 252001 (2013)



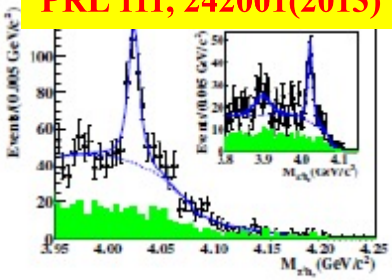
$e^+e^- \to \pi^-\pi^+ J/\psi$

Zc(3900)^0
PRL 115, 112003 (2015)



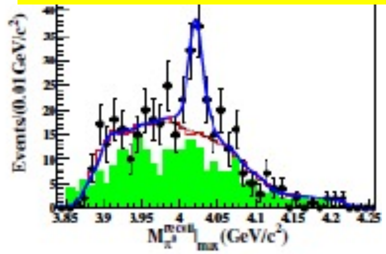
$e^+e^- \to \pi^0\pi^0 J/\psi$

Zc(4020)$^+$
PRL 111, 242001(2013)



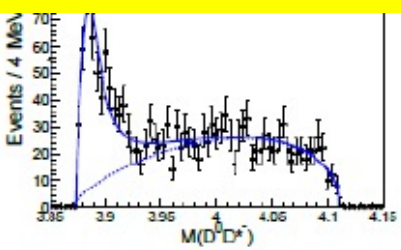
$e^+e^- \to \pi^-\pi^+ h_c$

Zc(4020)^0
PRL113,212002 (2014)



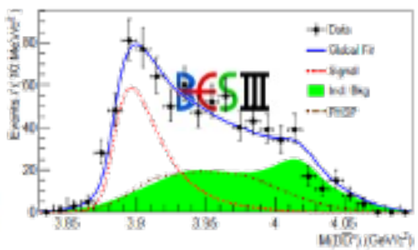
$e^+e^- \to \pi^0\pi^0 h_c$

Zc(3885)$^+$
ST: PRL 112, 022001(2014)
DT: PRD92, 092006 (2015)



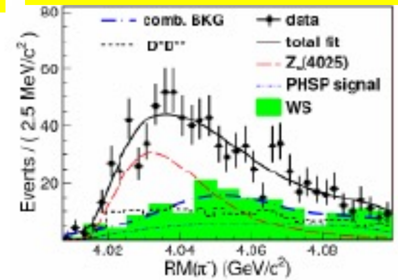
$e^+e^- \to \pi^-(D\bar{D}^*)^+$

Zc(3885)^0
PRL 115, 222002 (2015)



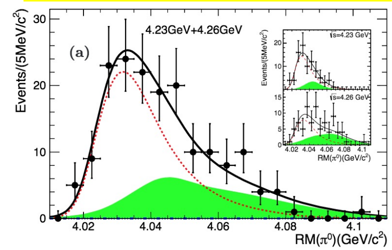
$e^+e^- \to \pi^0(D^*\bar{D})^0$

Zc(4025)$^+$
PRL 112, 132001 (2014)

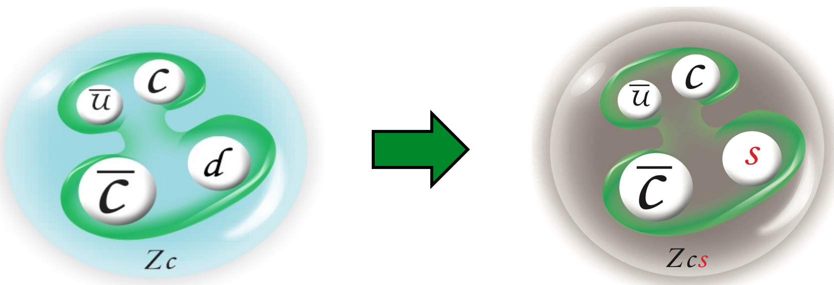


$e^+e^- \to \pi^-(D^*\bar{D}^*)^+$

Zc(4025)^0
PRL115, 182002 (2015)



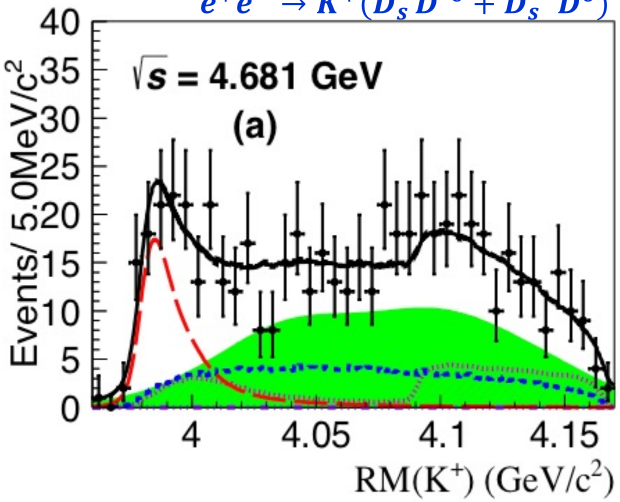
$e^+e^- \to \pi^0(D^*\bar{D}^*)^0$



Studies on the Z_{cs} states

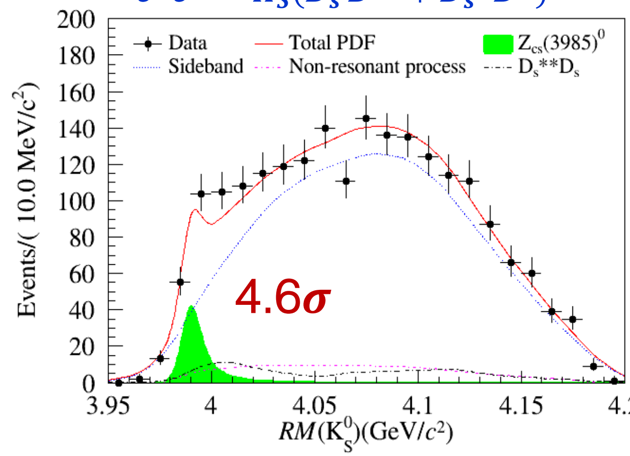
$Z_{cs}(3985)^+$ **PRL126, 102001 (2021)**

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



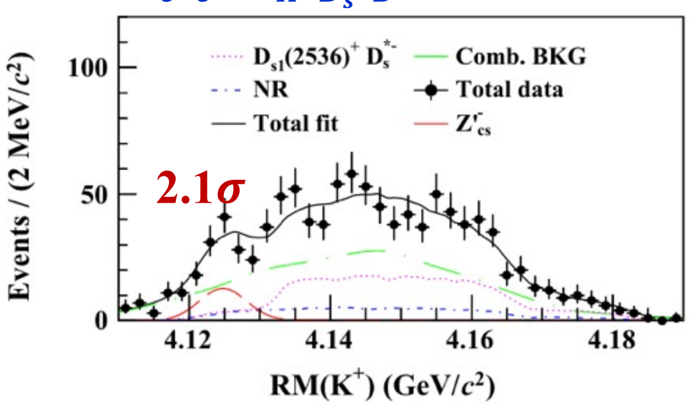
$Z_{cs}(3985)^0$ **PRL129, 112003 (2022)**

$e^+e^- \to K_S(D_s^- D^{*+} + D_s^{*-} D^+)$



Search for Z'_{cs} **CPC47, 033001 (2023)**

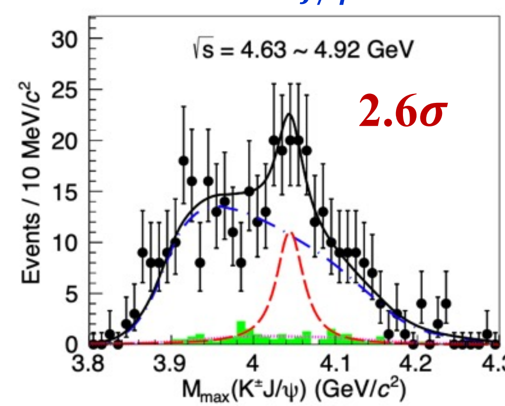
$e^+e^- \to K^+ D_s^{*-} D^{*0}$



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

Search for $Z_{cs}^+ \to K^+ J/\psi$ **arXiv:2308.15362**

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

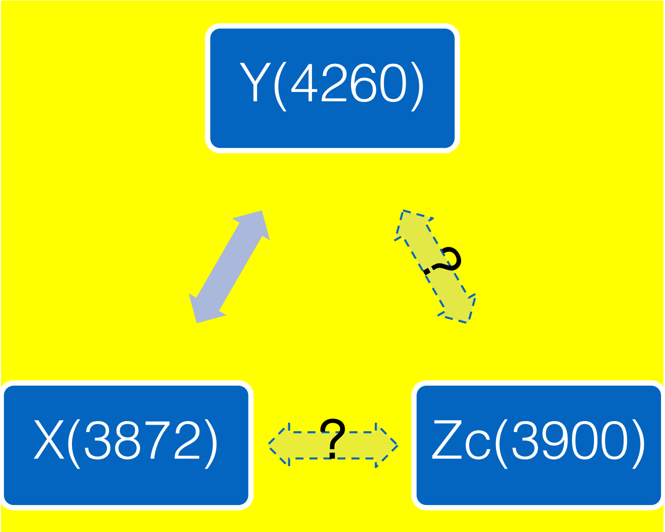


mass: $4044 \pm 6\ \text{MeV}/c^2$
width: 36 ± 16 MeV

BESIII Joint efforts among experiments and theories

- It is crucial that different experiments, such as BESIII, LHCb and Belle II, exchange information in the efforts of amplitude analyses
  - ✓ Sharing the knowledge on analysis tools
    eg, **TF-PWA** (talks given inside BESIII and LHCb) https://github.com/jiangyi15/tf-pwa
  - ✓ Constraints on properties of the hadronic states
- A few cases:
  - Zc/Zcs productions (e^+e^- annihilations or b-hadron decays) and decays (to open or hidden charm states)

State	Decay modes	Seen by	
$Z_c(3900)^{\pm,0}$	$\pi^{\mp}J/\psi$, $(D^*\overline{D})^{\mp}$	BESIII, Belle CLEO	in $e^+e^- \to \pi^- Zc$
$Z_c(4020)^{\pm,0}$	$\pi^{\mp}h_c$, $(D^*\overline{D}^*)^{\mp}$	BESIII	in $e^+e^- \to \pi^- Zc$
$Z_c(4430)^{\pm}$	$\pi^{\mp}\psi(2S)$ $\pi^{\pm}J/\psi$	Belle, ~~BaBar,~~ LHCb	in $B \to KZc$



- Energy-dependence
- Patterns in productions and decays

Pole properties

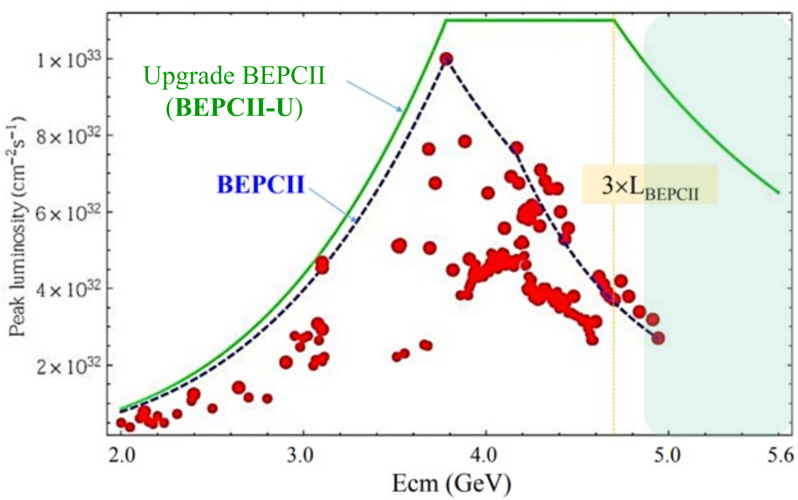
World-wide experimental efforts

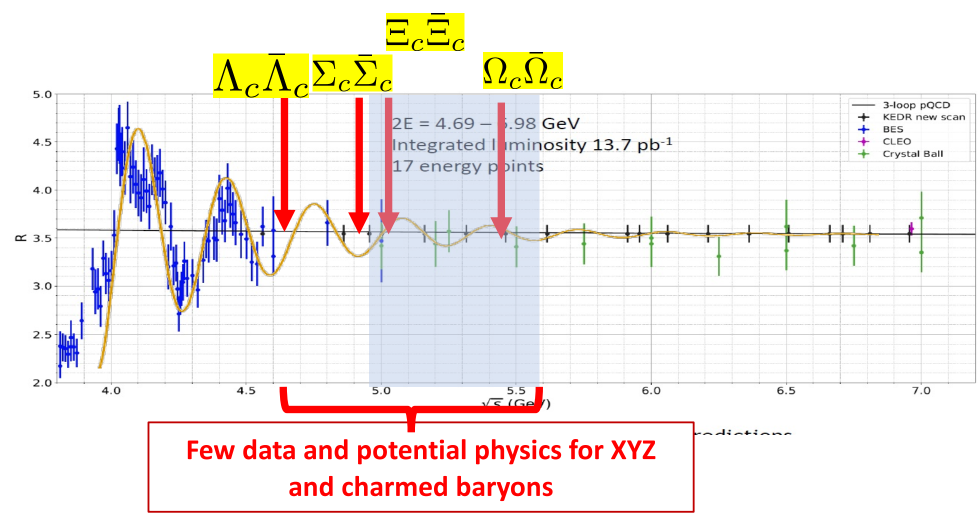
Models

LQCD

BEPCII-U in 2024

- ✓ Detailed studies of the known X/Y/$Z_{c(s)}$ 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





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
- Accomplish many precision measurements and new observations
  - ✓ 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, …
  - ✓ CPV search, 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!

Name	Mass(MeV/c^2)	Width(MeV)	Journal	arXiv
N(2570)	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	PhysRevLett.110, 022001	1207.0223
N(2300)	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	PhysRevLett.110, 022001	1207.0223
X(1870)	$1877.3\pm6.3^{+3.4}_{-7.4}$	$57\pm12^{+19}_{-4}$	PhysRevLett.107, 182001	1107.1806
X(1840)	$1842.2\pm4.1^{+7.1}_{-2.6}$	83±14±11	PhysRevD.88.091502	1305.5333
X(2500)	$2470^{+15+101}_{-19-23}$	230^{+64+56}_{-35-33}	PhysRevD.93.112011	1602.01523
X(2262)	2262±4±28	72±5±43	PhysRevD.104.052006	2104.08754
X(2120)	$2122.4\pm6.7^{+4.7}_{-2.7}$	$83\pm16^{+31}_{-11}$	PhysRevLett.106.072002	1012.3510
X(2370)	$2376.3\pm8.7^{+3.2}_{-4.3}$	$83\pm17^{+44}_{-6}$	PhysRevLett.106.072002	1012.3510
X(2600)	$2617.8\pm2.1^{+18.2}_{-1.9}$	$200\pm8^{+20}_{-17}$	PhysRevLett. 129, 042001	2201.10796
X(2356)	2356±7±17	304±28±54		2211.10755
f0(2480)	$2470\pm4^{+4}_{-6}$	$75\pm9^{+11}_{-8}$	PhysRevD 105, 072002	2201.09710
omega(2250)	2223±16±11	51±29±21	PhysRevD.105.032005	2112.15076
a0(1817)+-0	1817±8 ±20	97 ±22±15	PhysRevLett.129.182001	2204.09614
eta1(1855)	$1855\pm9^{+16}_{-1}$	$188\pm18^{+3}_{-8}$	PhysRevLett. 129, 192002	2202.00621
Y(4390)	$4391.6^{+6.3}_{-6.9}\pm1.0$	$139.5^{+16.2}_{-20.6}\pm0.6$	PhysRevLett. 118, 092002	1610.07044
Y(4320)	4320.0±10.4±7.0	$1101.4^{+25.3}_{-19.7}\pm10.2$	PhysRevLett. 118, 092001	1611.01317
Y(4230)	4222.0±3.1±1.4	44.1±4.3±2.0	PhysRevLett. 118, 092001	1611.01317
Y(4790)	4793.3±7.5	27.1±7.0		2305.10789
psi2(3823)	3821.7 ± 1.3 ± 0.7	<16	PhysRevLett.115.011803	1503.08203
Y(4500)	4484.7±13.3±24.1	111.1±30.1±15.2	Chin.Phys.C,46,111002	2204.07800
Zc(3900)+-	3899.0±3.6±4.9	46±10±20	PhysRevLett.110.252001	1303.5949
Zc(3900)0	3894.8±2.3±3.2	29.6±8.2±8.2	PhysRevLett.115.112003	1506.06018
Zc(4020)+-	4022.9 ± 0.8 ± 2.7	7.9 ± 2.7 ± 2.6	PhysRevLett.111.242001/ PhysRevLett.112.132001	1309.1896/ 1308.2760
Zc(4020)0	4023.9±2.2±3.8	7.9(Fixed)	PhysRevLett.113.212002	1409.6577
Zcs(3985)+-	$3982^{+1.8}_{-2.6}\pm2.1$	$12.8^{+5.3}_{-4.4}\pm3.0$	PhysRevLett.126.102001	2011.07855