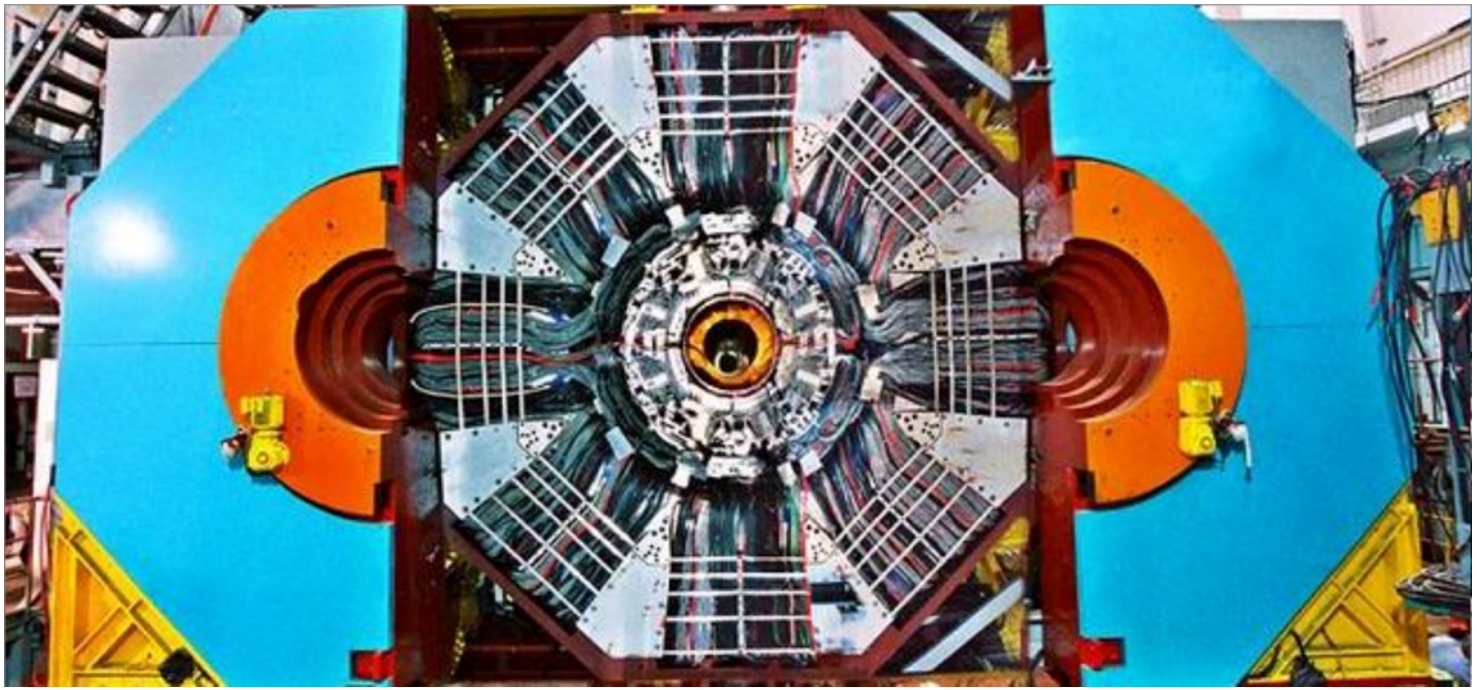


Recent results and future prospects on the BESIII experiment

Xiao-Rui Lyu（吕晓睿）

University of Chinese Academy of Sciences (UCAS)

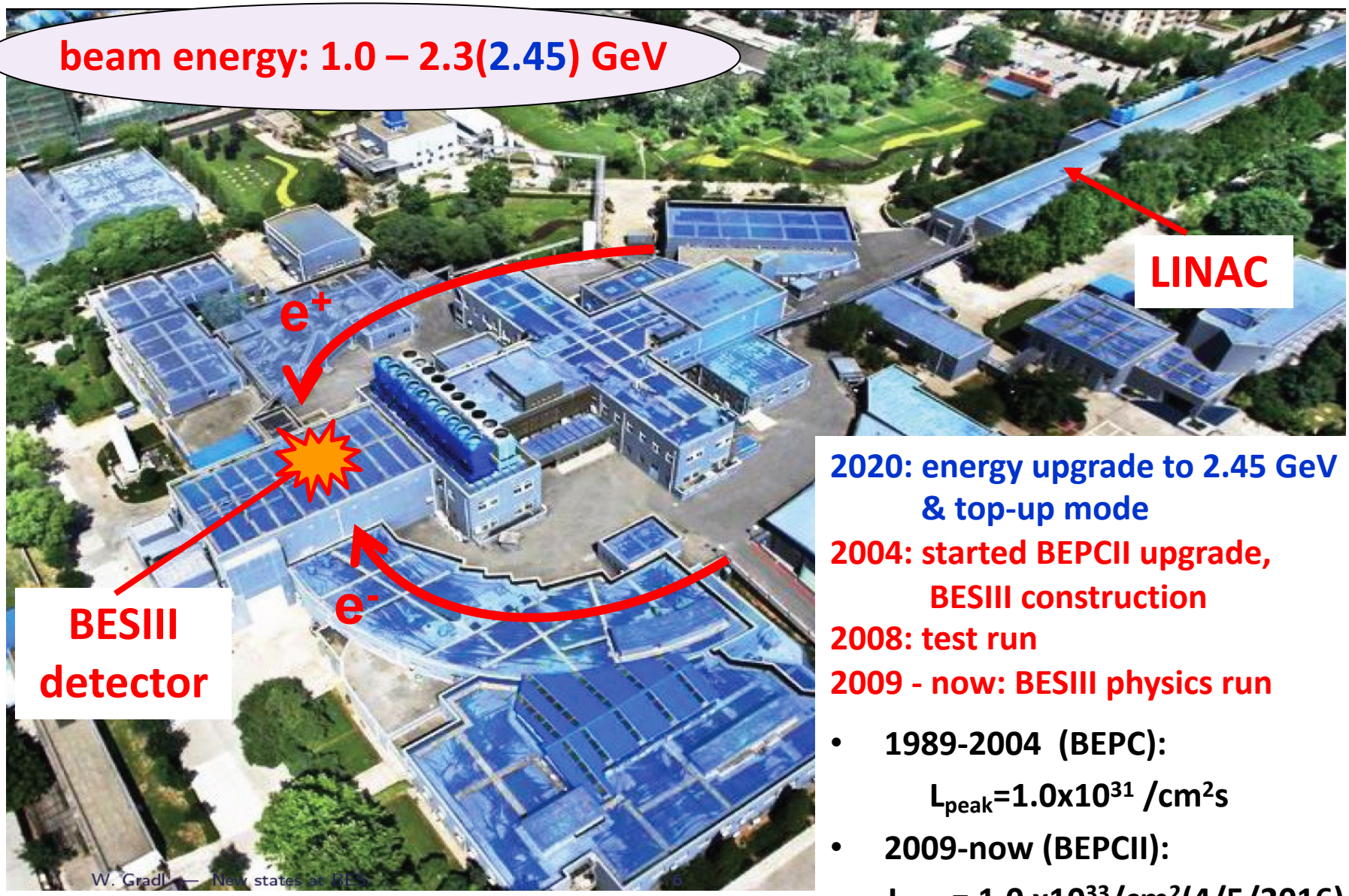
(On behalf of the BESIII collaboration)

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):

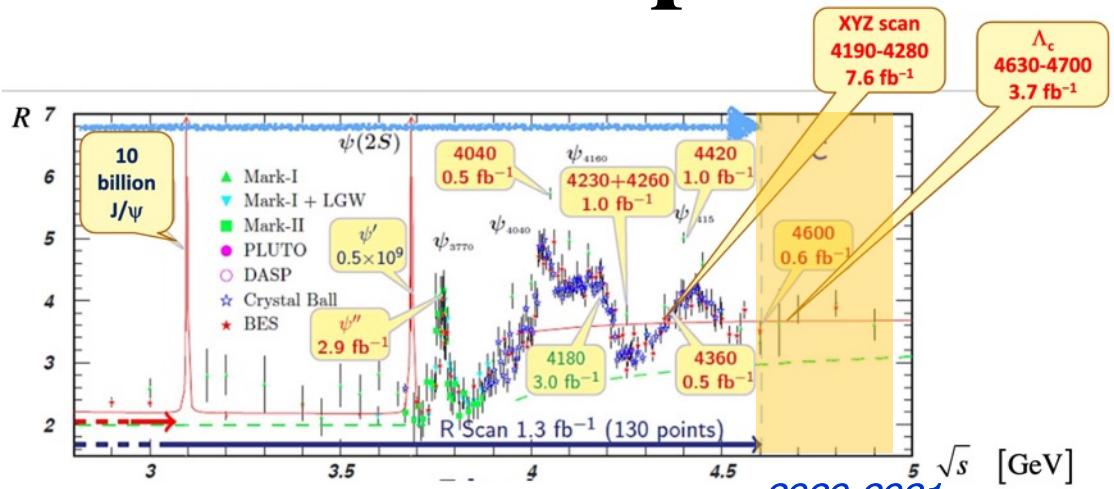
  $L_{peak}=1.0\times10^{31}$ /cm^{2}s

- 2009-now (BEPCII):

  $L_{peak}= 1.0\times10^{33}$/cm^2(4/5/2016)

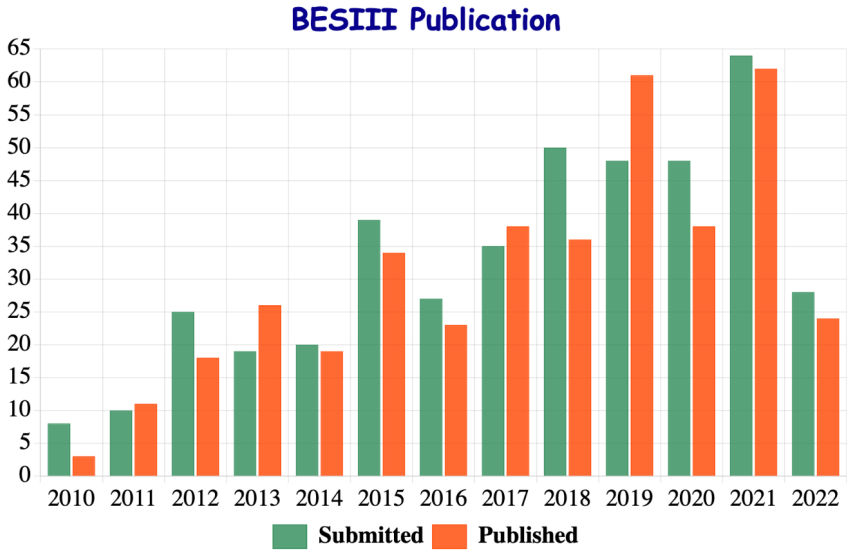
BESIII data sample

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

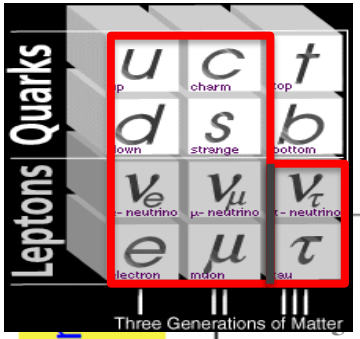


2020-2021

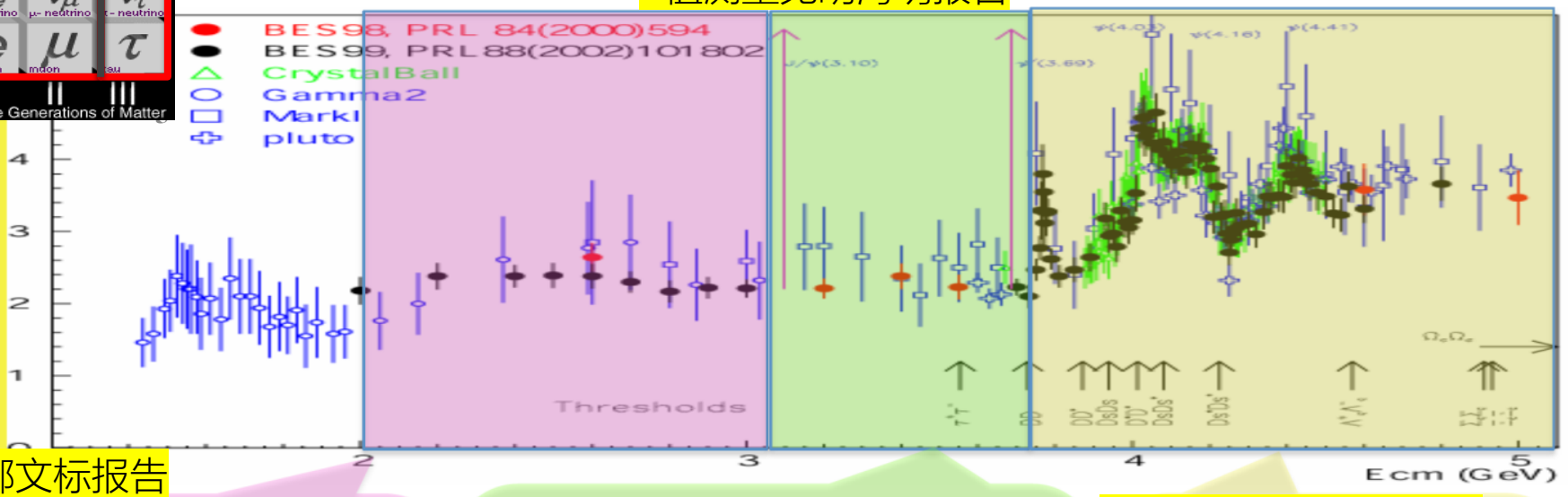
2020: 3.8 fb^{-1} scan **4.61-4.7 GeV**
2021: 2 fb^{-1} scan **4.74-4.95 GeV**; 2.55B ψ(2S)
2022: 5.1 fb^{-1} at ψ(3770)



Physics at tau-charm Energy Region



R值测量见胡海明报告



见鄢文标报告

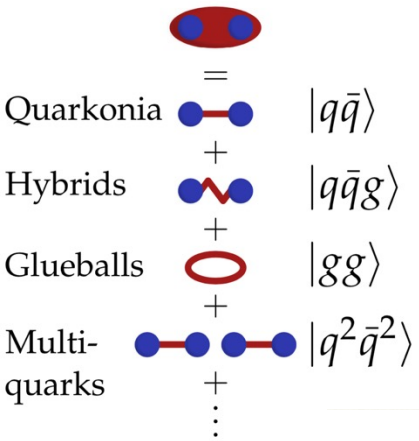
- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

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

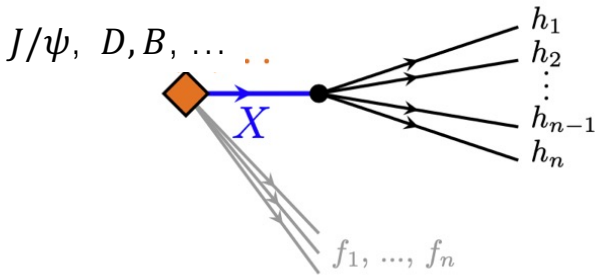
见马海龙、张书磊报告

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

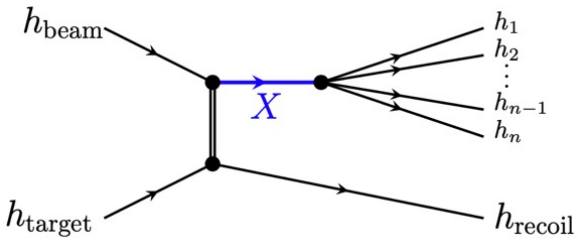
Light hadron spectroscopy

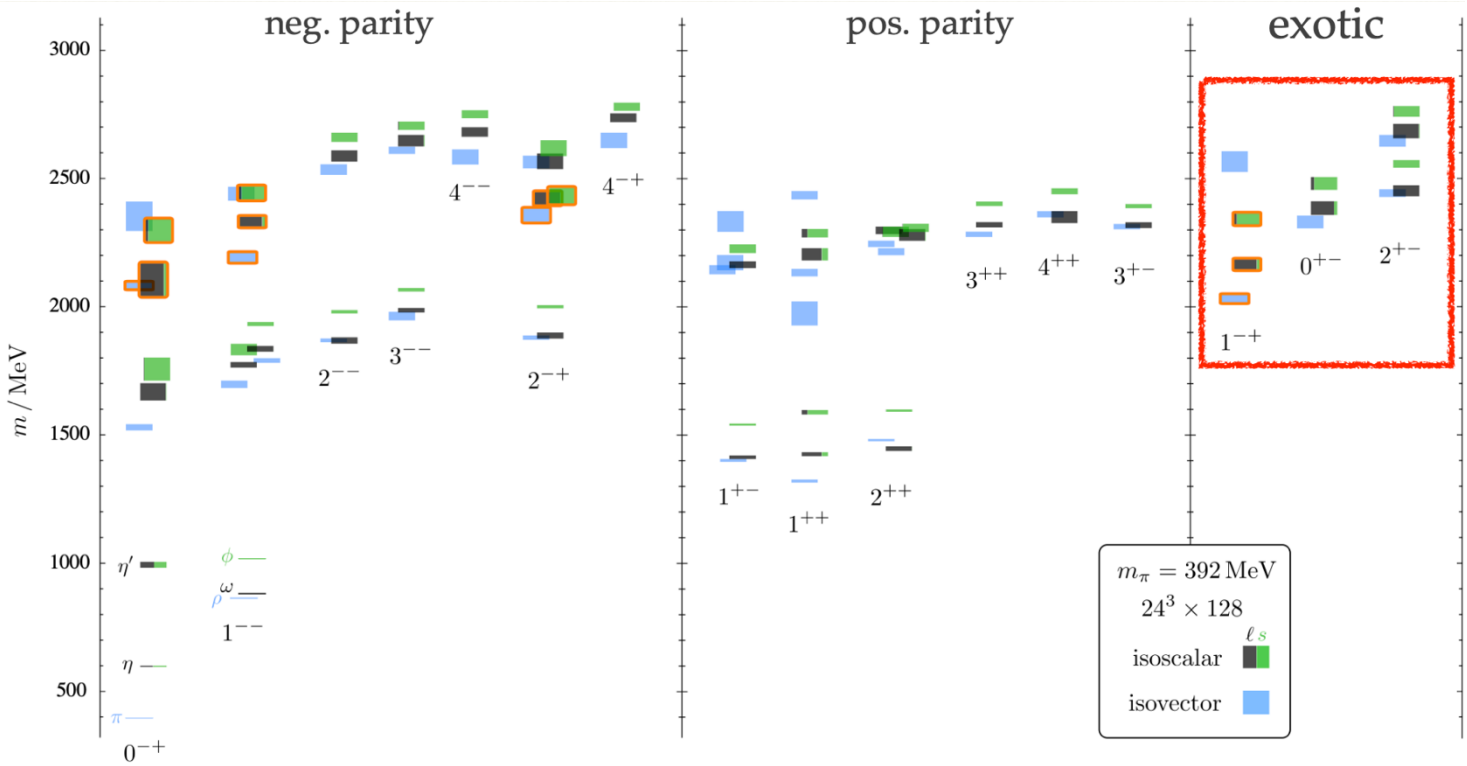


BESIII, LHCb, Belle (II) …



GlueX, Compass, …





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

arXiv:2202.00621
arXiv:2202.00623

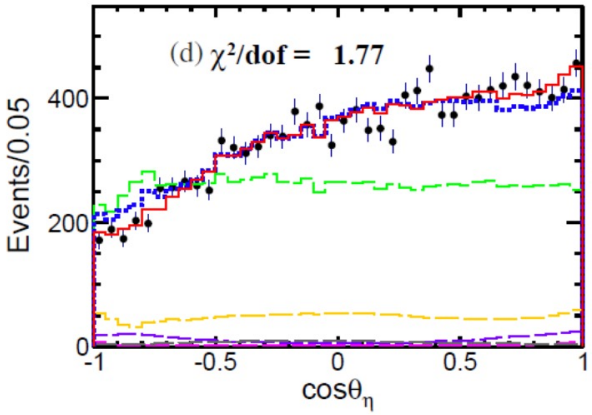
based on 10B J/ψ events

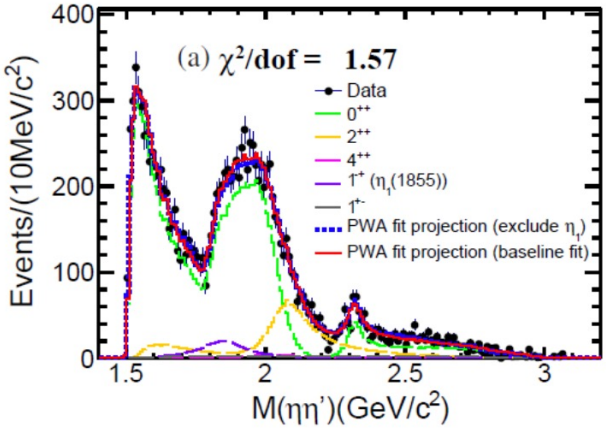
- The η' is reconstructed from $\gamma\pi^+\pi^-$ & $\eta\pi^+\pi^-$, η from $\gamma\gamma$
- Partial wave analysis of $J/\psi \to \gamma\eta\eta'$

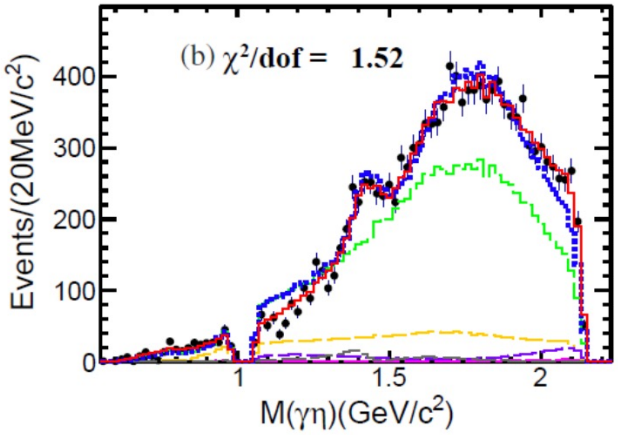
  Quasi two-body decay amplitudes in the sequential decay processes $J/\psi \to \gamma X, X \to \eta\eta'$ and $J/\psi \to \eta X, X \to \gamma\eta'$ and $J/\psi \to \eta' X, X \to \gamma\eta$ are constructed using the covariant tensor formalism[5]

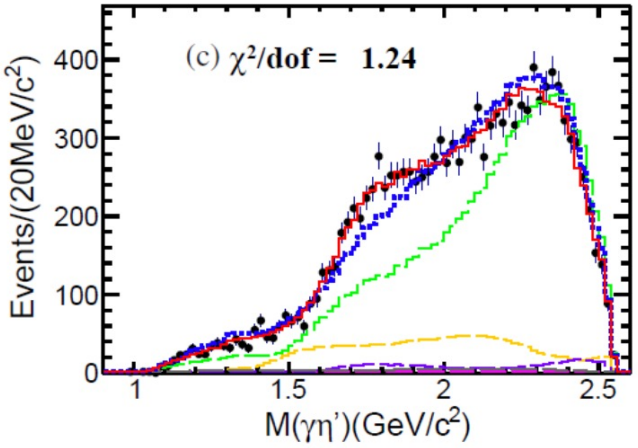
- All kinematically allowed known resonances with 0^{++}, 2^{++}, 4^{++} $(\eta\eta')$ and 1^{+-}, $1^{-+}(\gamma\eta^{(\prime)})$ are considered

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









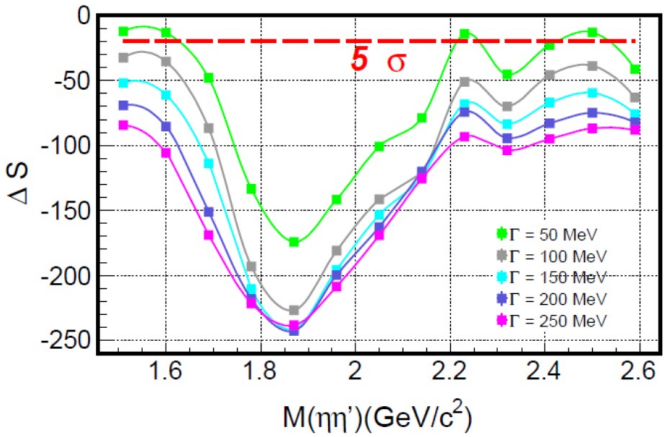
Observation of exotic isoscalar meson $\eta_1(1855)(1^{-+})$

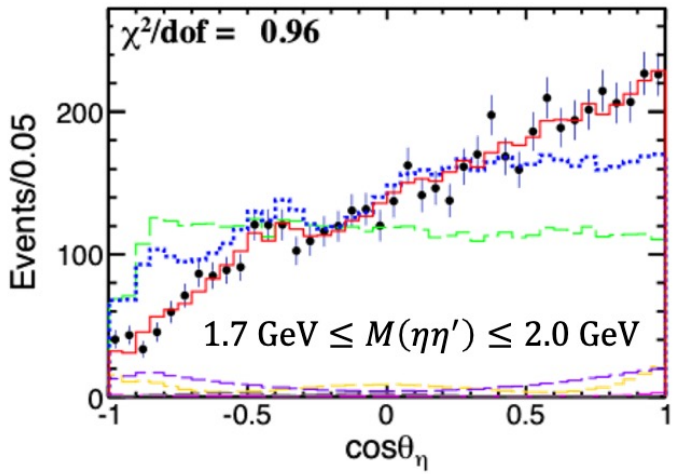
arXiv:2202.00621
arXiv:2202.00623

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

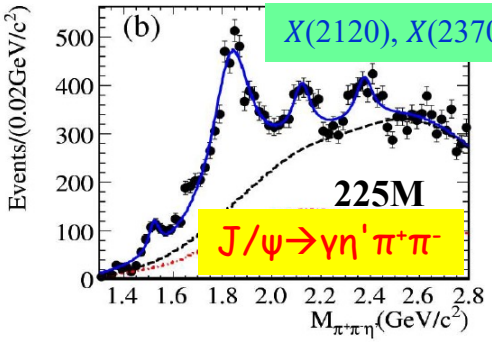
Hybrid?
Molecule?
Tetraquark?

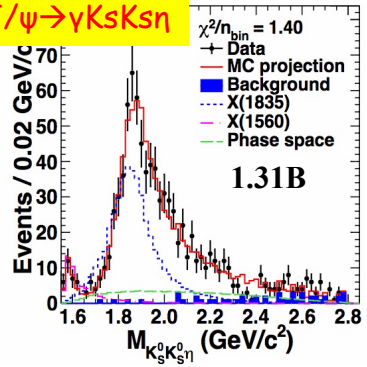
- Assuming $\eta_1(1855)$ is an additional resonance, scans of with different masses and widths
- Significant 1^{-+} contribution around **1.8 GeV/c^2** needed

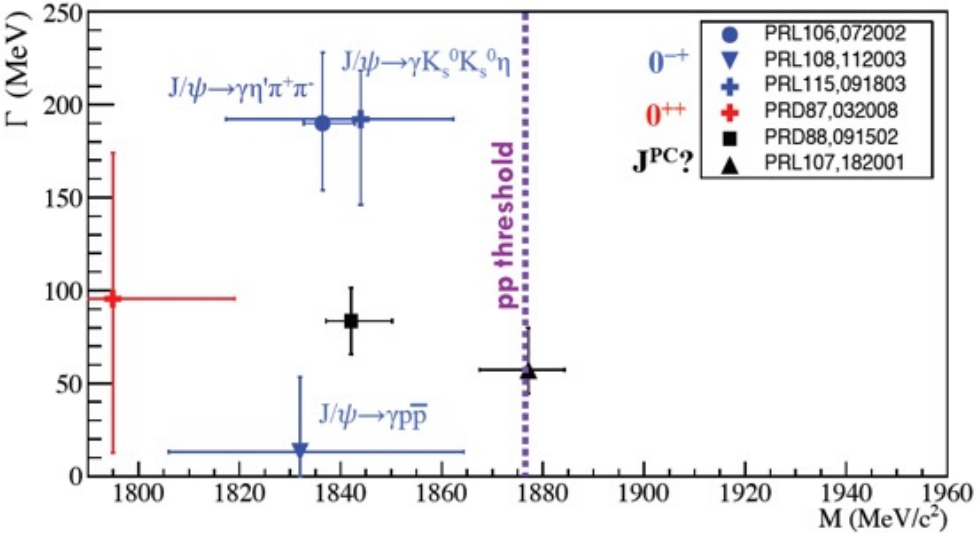


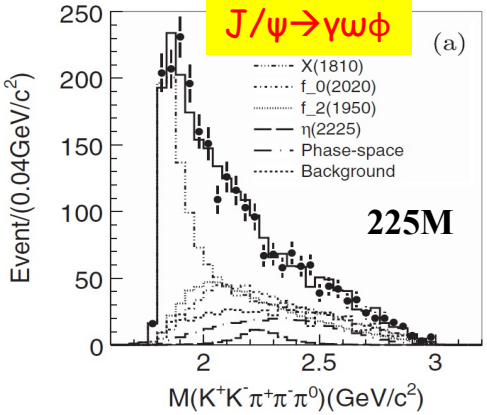


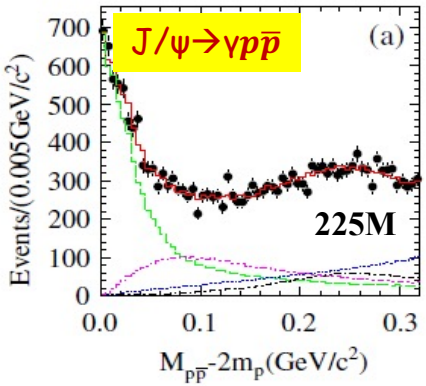
X($p\bar{p}$)/X(18??) from J/ψ radiative decays





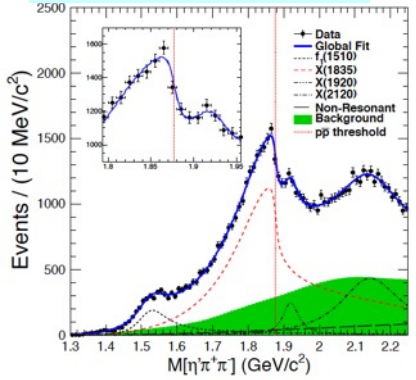






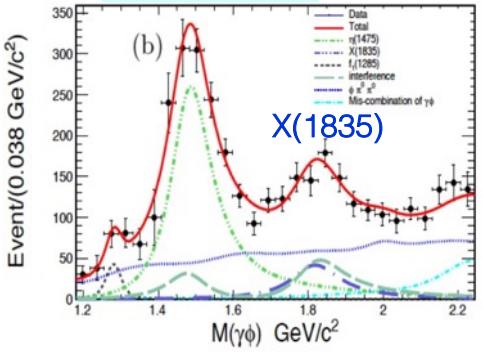
PRL117, 042002 (2016)

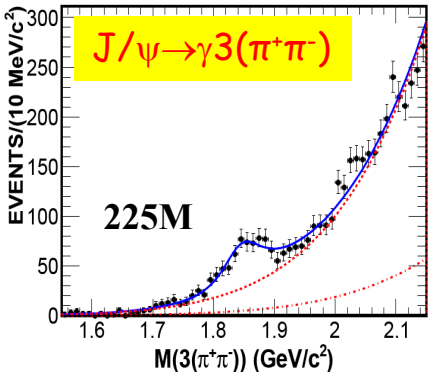
$J/\psi\to\gamma\eta'\pi^+\pi^-$

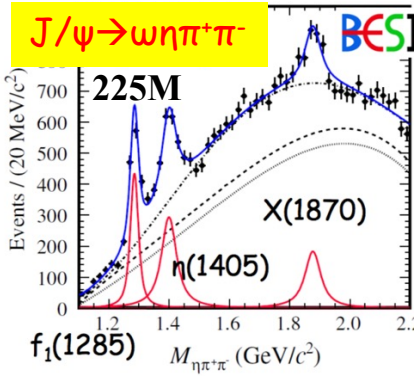


PRD97, 051101(R)(2018)

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







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

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

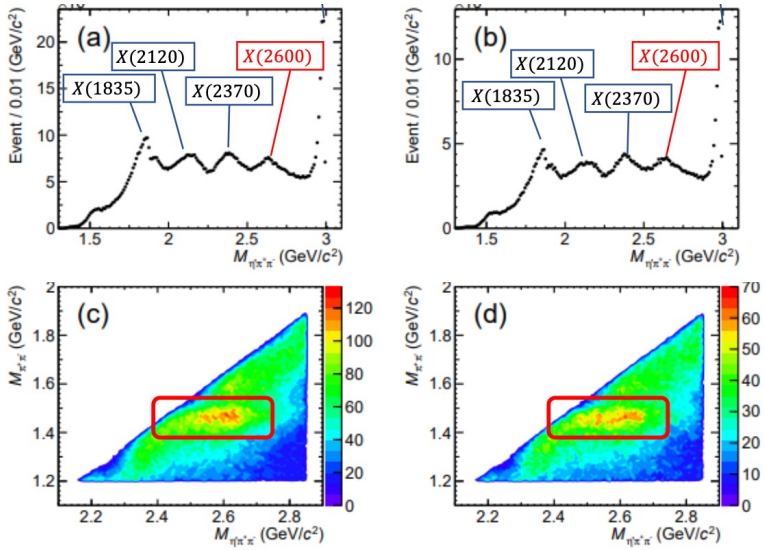
PRL129, 042001 (2022)

- 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 $f_2'(1525)$ in $\pi^+\pi^-$

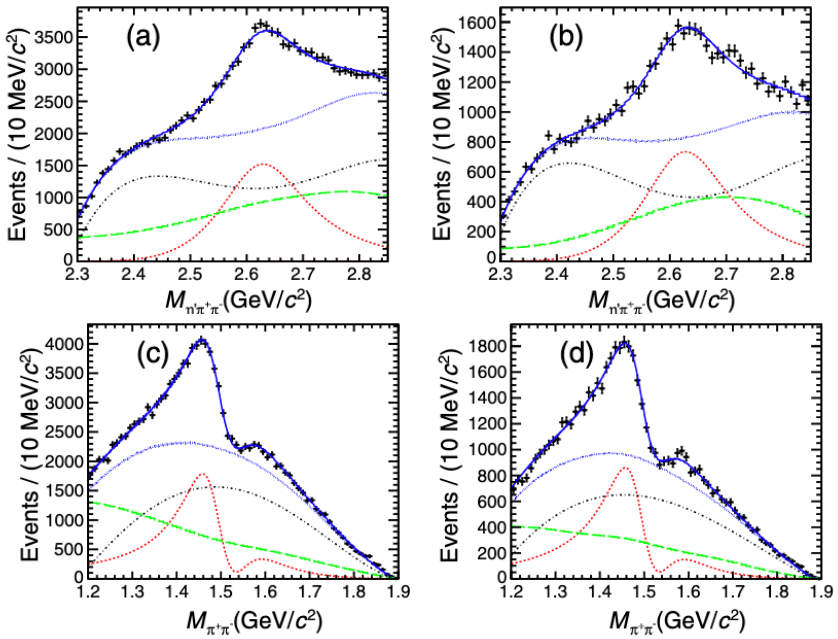
Resonance	Mass (MeV/c^2)	Width (MeV)
$f_0(1500)$	$1492.5 \pm 3.6^{+2.4}_{-20.5}$	$107 \pm 9^{+21}_{-7}$
$X(1540)$	$1540.2 \pm 7.0^{+36.3}_{-6.1}$	$157 \pm 19^{+11}_{-77}$
$X(2600)$	$2618.3 \pm 2.0^{+16.3}_{-1.4}$	$195 \pm 5^{+26}_{-17}$

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)

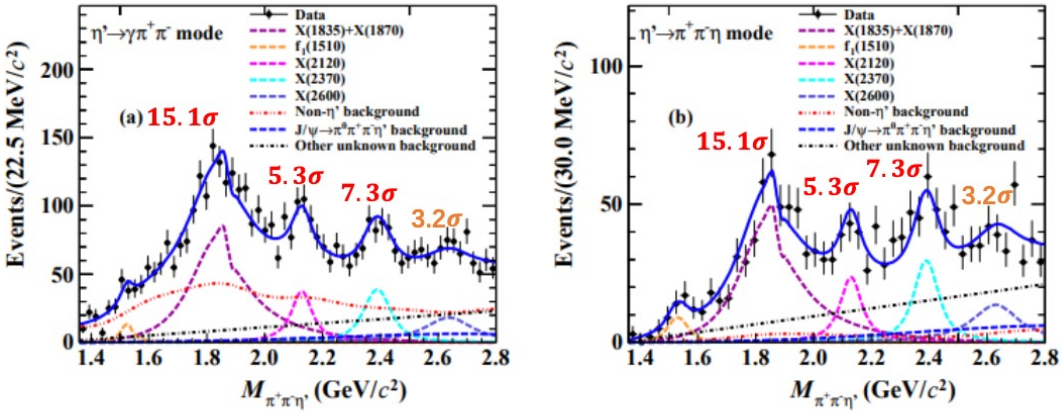


- $X(2600)$: 0^{-+} or 2^{-+} is favored. η radial excitation, or exotics?
- $X(1540)$: $f_2'(1525)$ or $f_2(1565)$?

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

PRL129, 022002(2022)

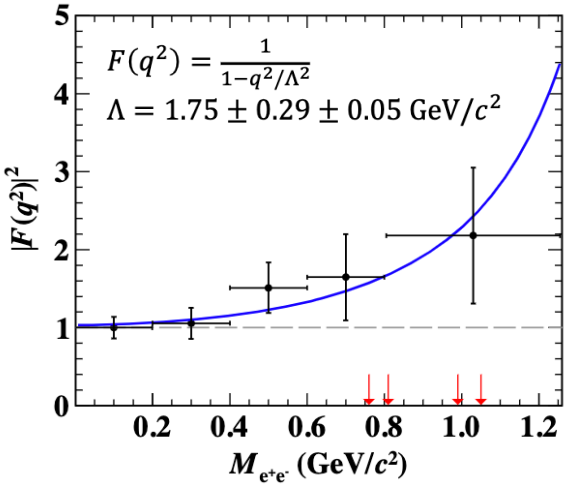
- Observation of X(1835), X(2120), and X(2370) in EM Dalitz decays
- First measurement of the TFF between J/ψ and X(1835)



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

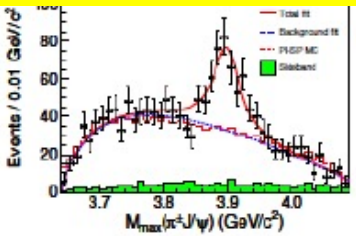
$$\frac{d\Gamma(J/\psi \to X(1835)e^+e^-)}{dq^2\Gamma(J/\psi \to X(1835)\gamma)} = |F(q^2)|^2 \times [\mathrm{QED}(q^2)],$$



The Zc Family at BESIII

$Zc(3900)^+$

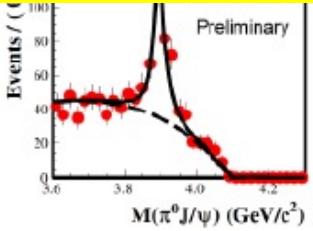
PRL 110, 252001 (2013)



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

$Zc(3900)^0$

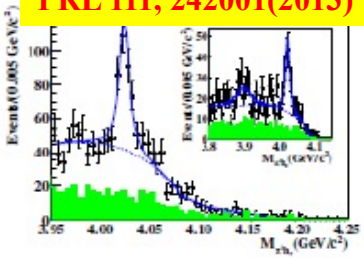
PRL 115, 112003 (2015)



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

$Zc(4020)^+$

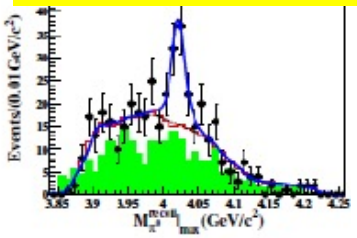
PRL 111, 242001(2013)



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

$Zc(4020)^0$

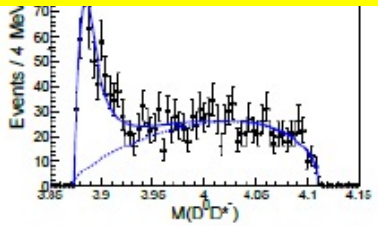
PRL113,212002 (2014)



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

$Zc(3885)^+$

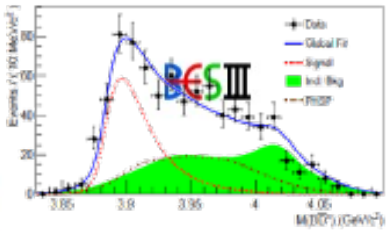
ST: PRL 112, 022001(2014)
DT: PRD92, 092006 (2015)



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

$Zc(3885)^0$

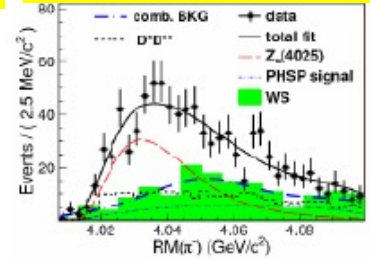
PRL 115, 222002 (2015)



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

$Zc(4025)^+$

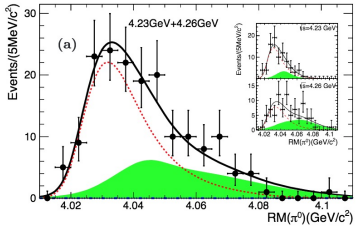
PRL 112, 132001 (2014)



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

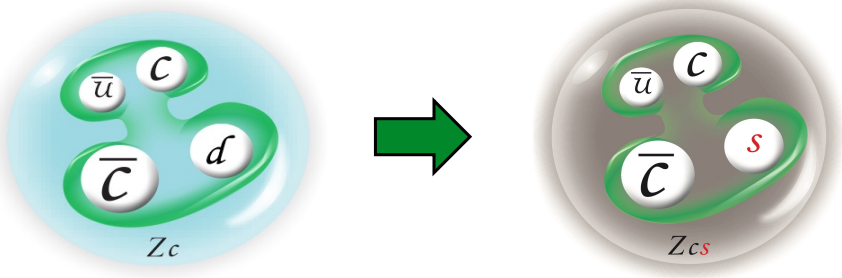
$Zc(4025)^0$

PRL115, 182002 (2015)



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

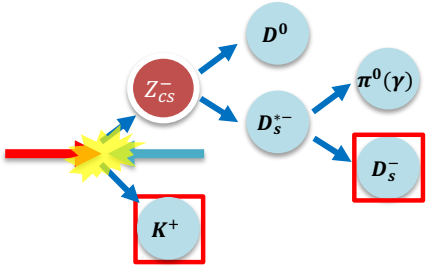
Which is the nature of these states?
If exists, there should be SU(3) counter-part Zcs state with strangeness



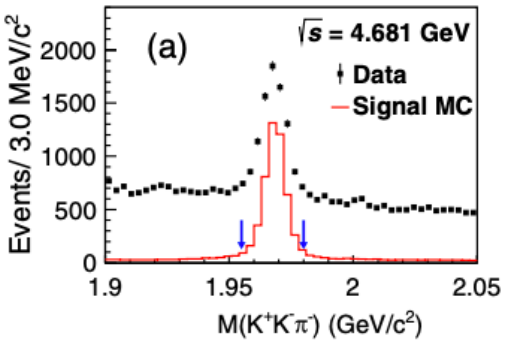
Observation of the $Z_{cs}(3985)^{\pm}$

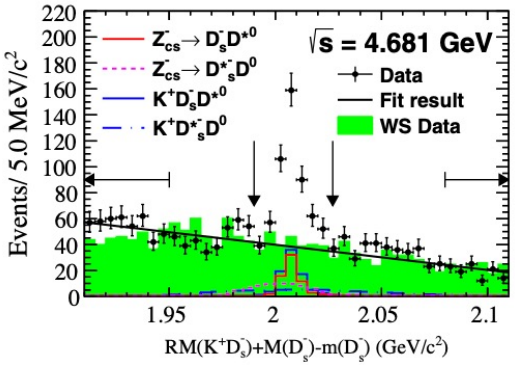
PRL126, 102001 (2021)

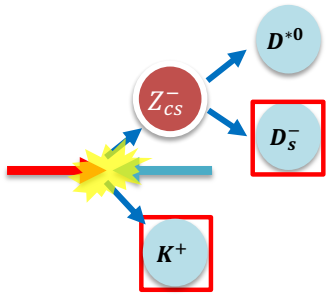
- 3.7fb^{-1} data accumulated at 4.628-4.698 GeV
- **Partial reconstruction of K^+ and D_s^-**
- Signature in the **recoil mass spectrum of $K^+D_s^-$** to identify the process of $e^+e^- \to K^+(D_s^-D^{*0} + D_s^{*-}D^0)$



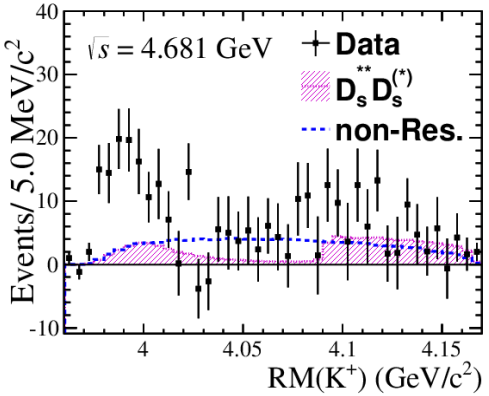
$e^+e^- \to K^+D_s^{*-}D^0$

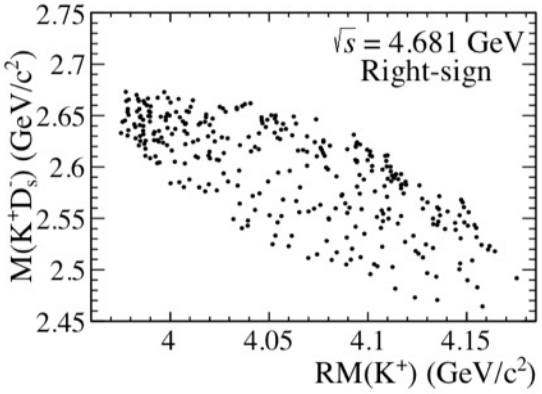


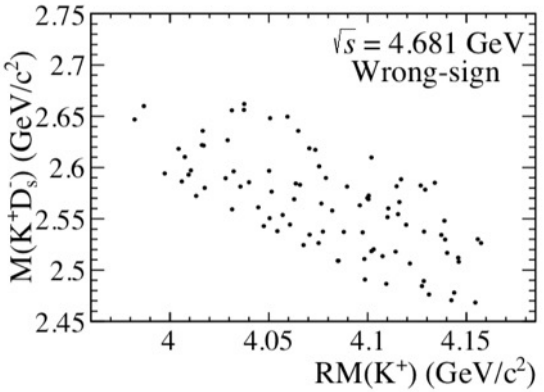




$e^+e^- \to K^+D_s^-D^{*0}$

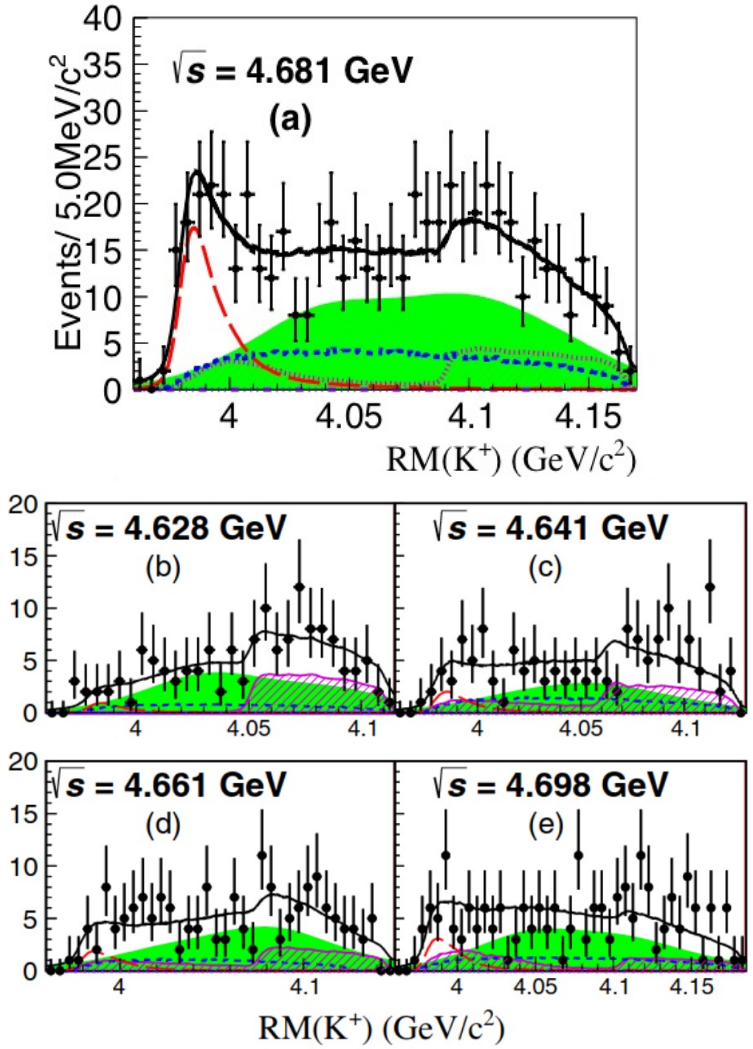






Observation of the $Z_{cs}(3985)^{\pm}$

PRL126, 102001 (2021)

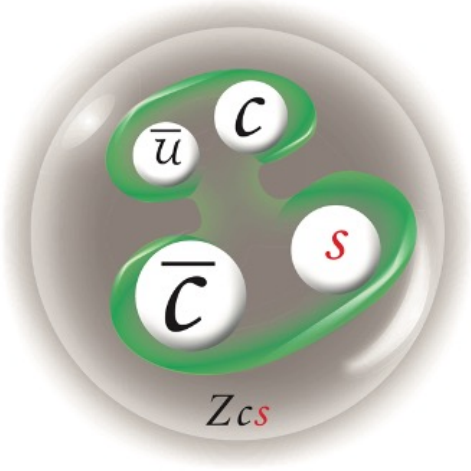


- Assume the structure as a $D_s^- D^{*0}/D_s^{*-} D^0$ resonance, denoting it as the $Z_{cs}(3985)^-$.
- A fit of $J^P=1^+$ S-wave Breit-Wigner with mass dependent width returns:

$$\boldsymbol{m} = 3985.2^{+2.1}_{-2.0} \pm 1.7\ \mathrm{MeV/c^2}$$

$$\boldsymbol{\Gamma} = 13.8^{+8.1}_{-5.2} \pm 4.9\ \mathrm{MeV}$$

- Global significance: >5.3 $\boldsymbol{\sigma}$



First candidate of the hidden-charm tetraquark with strangeness

The Zcs (3985)$^{\pm}$ and Zc(3885)$^{\pm}$

	1643/pb data @4.681 GeV	525/pb data @4.26 GeV	
	$Z_{cs}(3985)^{\pm}$	$Z_c(3900)^{\pm}$	$Z_c(3885)^{\pm}$
Mass (MeV/c^2)	$3985.2^{+2.1}_{-2.0} \pm 1.7$	3899.0±3.6±4.9	3883.9±1.5±4.2
Width (MeV)	$13.8^{+8.1}_{-5.2} \pm 4.9$	46±10±26	24.8±3.3±11.0
$\sigma^{Born} \cdot \mathcal{B}$ (pb)	$4.4^{+0.9}_{-0.8} \pm 1.4$	13.5±2.1±4.8	83.5±6.6±22.0

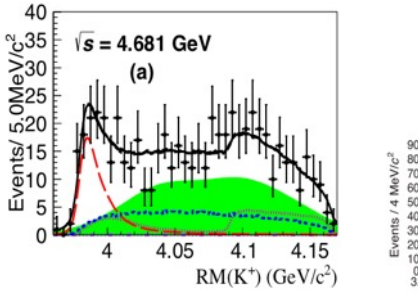
~10 MeV above D_sD^*/D_sD thresholds
similar to $Z_c(3900)$ & $Z_b(10,610)$
(DD*) (BB*)

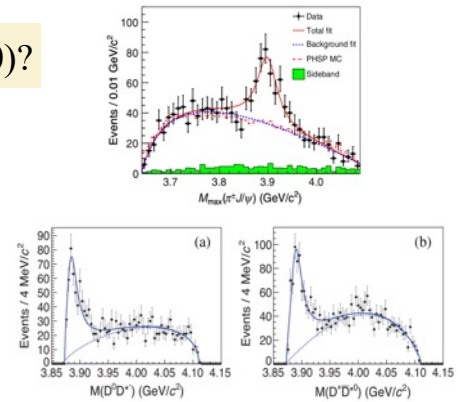
from Marek Karliner in Nov. 2020

two general comments about
charm-tau factory program

- $J/\psi\, K^{\pm}$ resonances:
  $Z_c(3900)$ analogue?
  $Z_c(3900)^+ = (c\bar{c}u\bar{d})$; $d \to s$: $(c\bar{c}u\bar{s}) \sim D_s\bar{D}^*$
  no natural molecular binding,
  so if discovered, would indicate
  Tq or a novel mechanism

SU(3) partner of Zc(3900)?





$Z_{cs}(3985)$

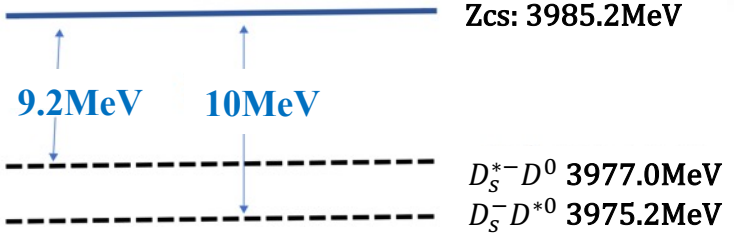
$K^-Z_{cs}^+$	$\bar{K}^0Z_{cs}^0$	$K^0\bar{Z}_{cs}^0$	$K^+Z_{cs}^-$
1/4	1/4	1/4	1/4

neutral/charged = 1

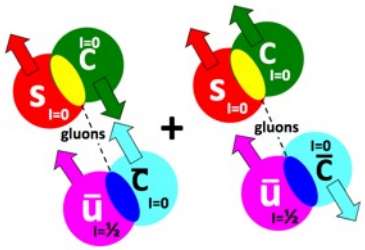
$Z_c(3900)$

$\pi^-Z_c^+$	$\pi^0Z_c^0$	$\pi^+Z_c^-$
1/3	1/3	1/3

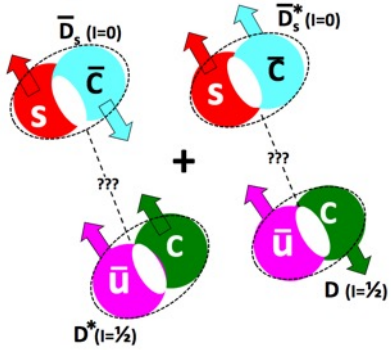
neutral/charged = 1/2



diquark-antidiquark?



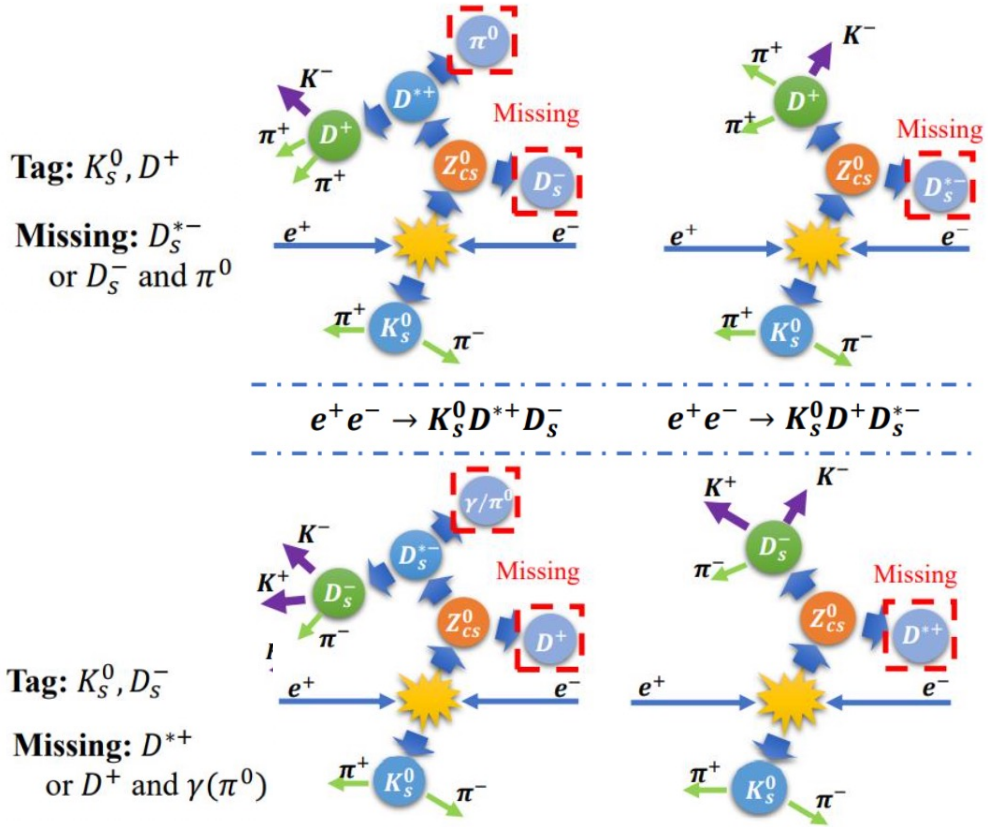
$D^*\bar{D}_s$ + cc molecule?

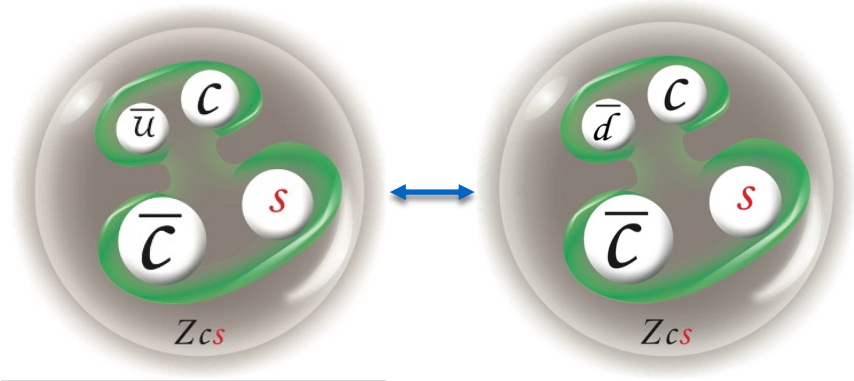


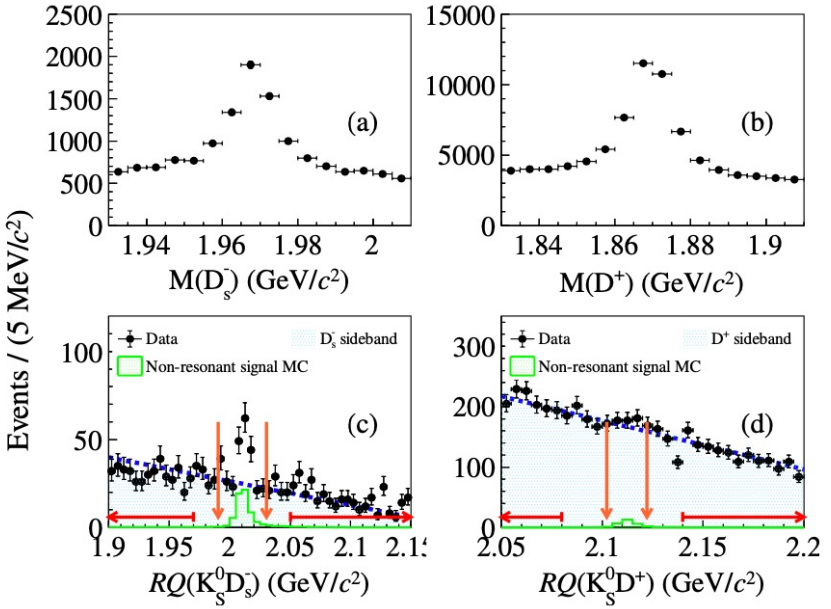
Evidence for the neutral $Z_{cs}(3985)^0$

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

arXiv 2204.13703, accepted by PRL

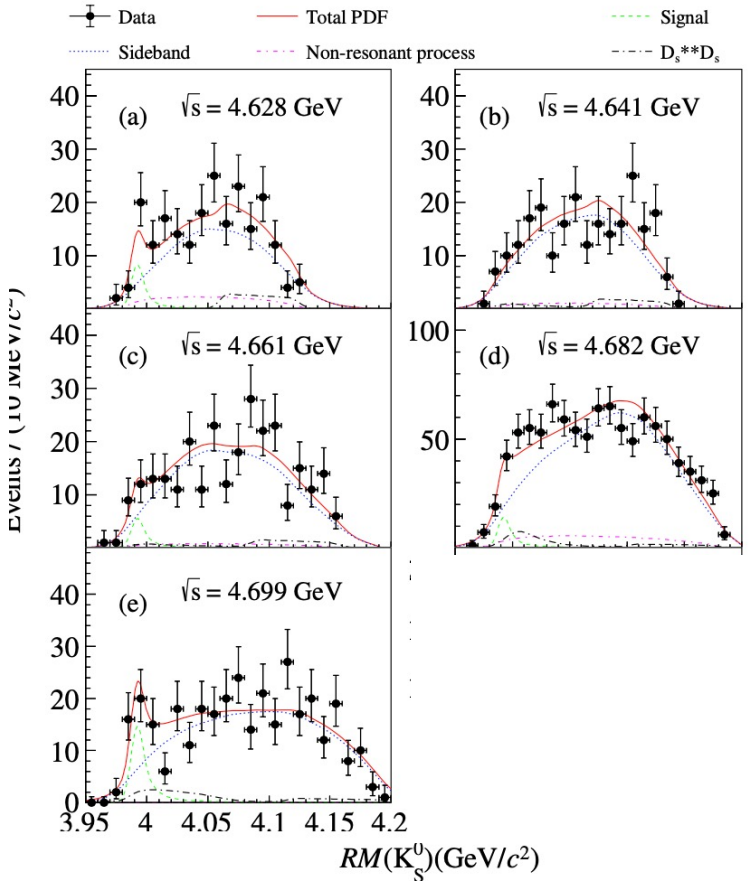




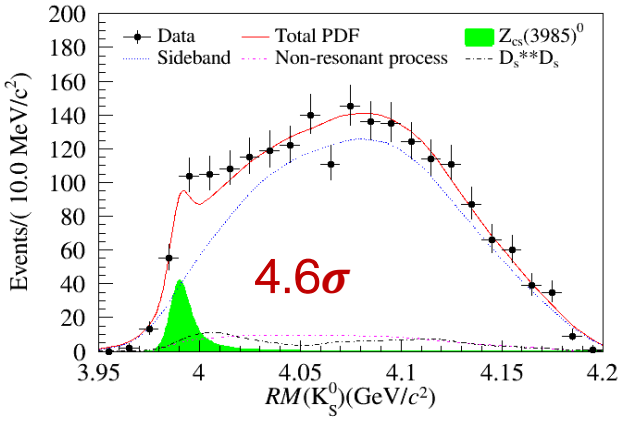


- The D_s^+ and D^+ are reconstructed through
  - $D_s^- \to K^+K^-\pi^-$, $K^+K^-\pi^-\pi^0$, $K_S^0K^-$, $K_S^0K^+\pi^-\pi^-$, $\eta'\pi^-$
  - $D^+ \to K^-\pi^+\pi^+$, $K_S^0\pi^+$, $K_S^0\pi^+\pi^+\pi^-$

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



arXiv 2204.13703 accepted by PRL



$\sqrt{s}$ (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

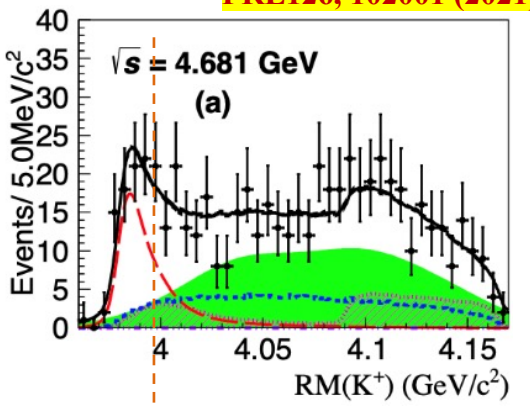
Discussions on the nature of $Z_{cs}(3985)$

- 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
  - …

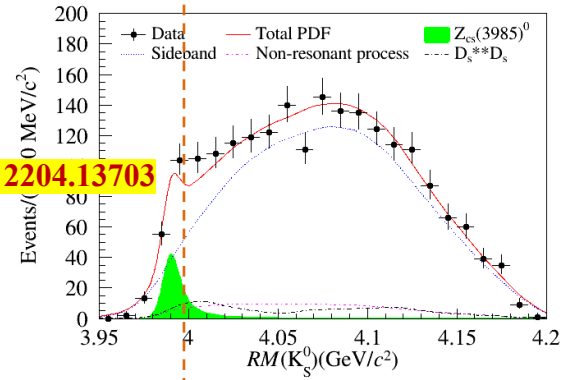
$Z_{cs}(3985)$ from $e^{+}e^{-}$ annihilations and $Z_{cs}(4000)$ from B decays

- 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

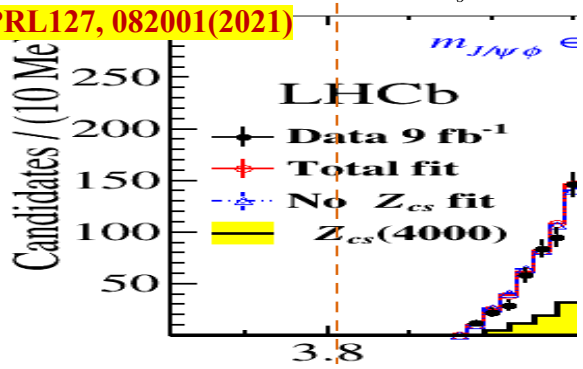
PRL126, 102001 (2021)



arXiv 2204.13703

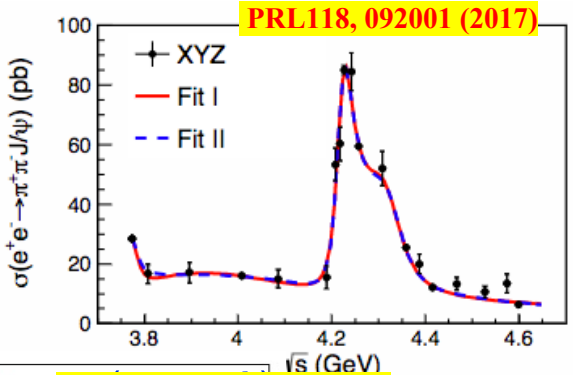


PRL127, 082001(2021)

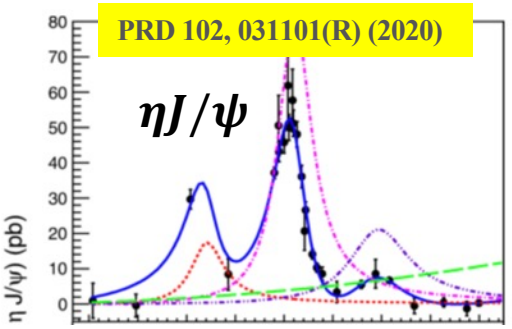


Y(4260) ➔ Y(4230) and new Y's

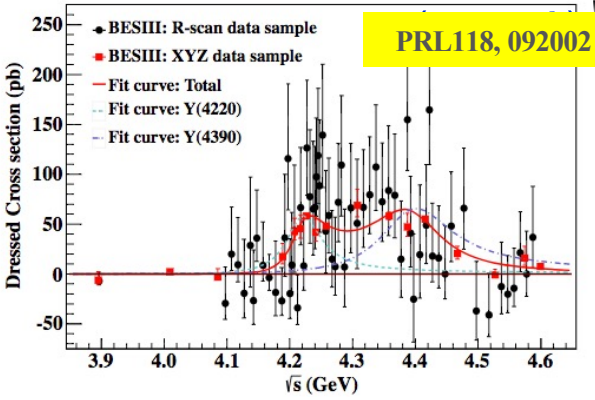
PRL118, 092001 (2017)



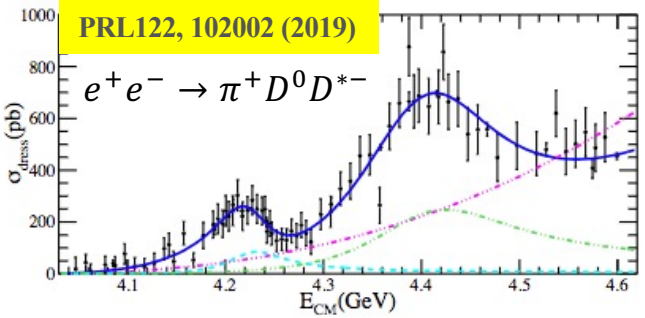
PRD 102, 031101(R) (2020)



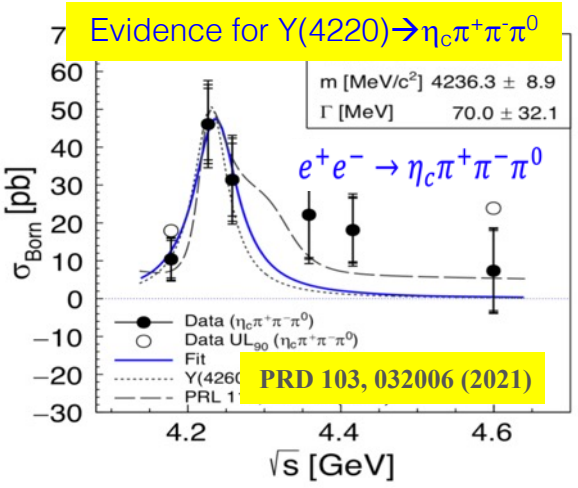
PRL118, 092002 (2017)



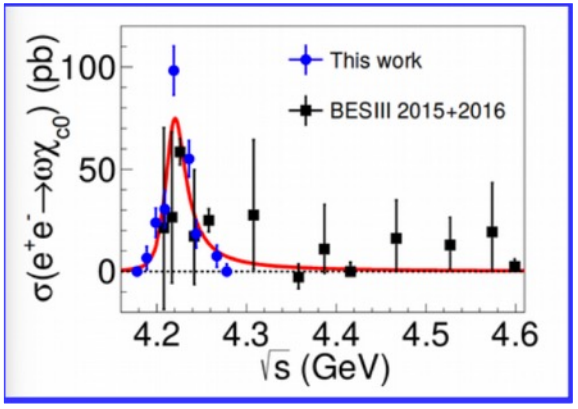
PRL122, 102002 (2019)



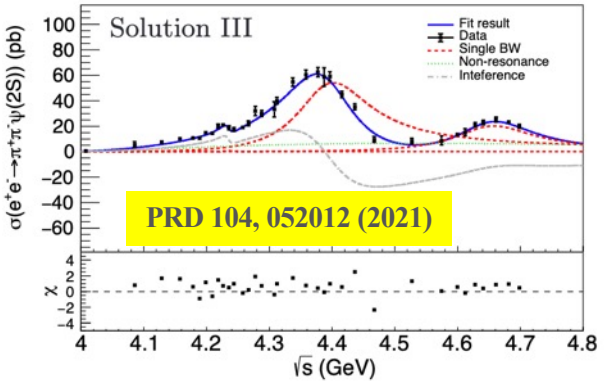
Evidence for Y(4220)→$\eta_c\pi^+\pi^-\pi^0$



PRD 103, 032006 (2021)

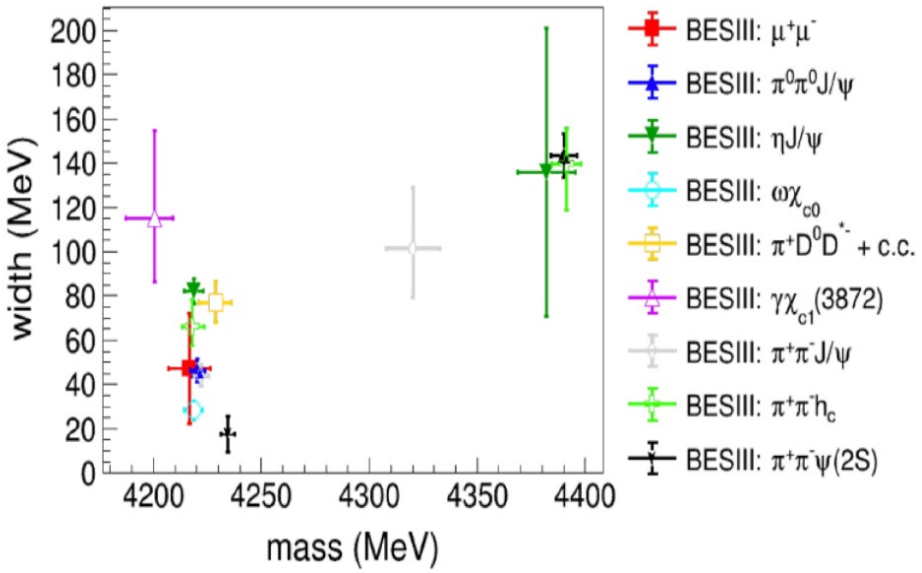


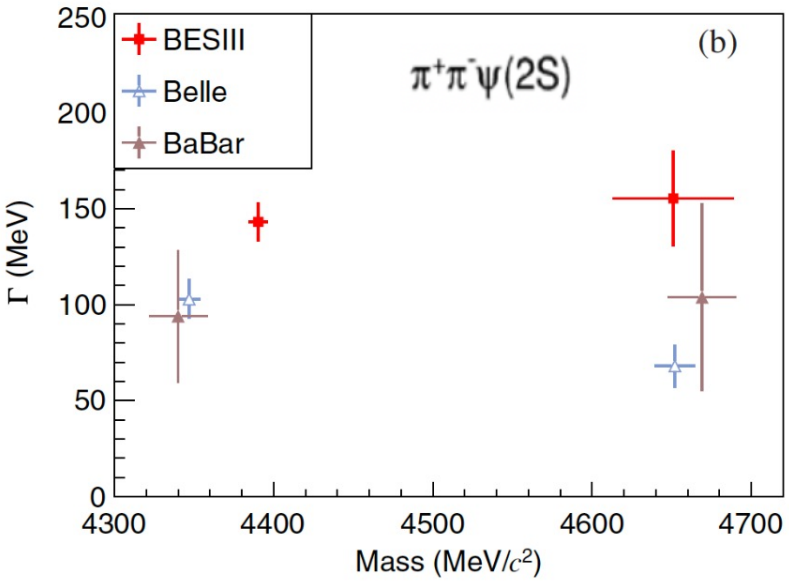
confirmed Y(4220), Y(4390) and Y(4660)



PRD 104, 052012 (2021)

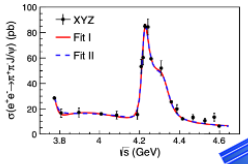
Y(4230), Y(43XX) and Y(4660)



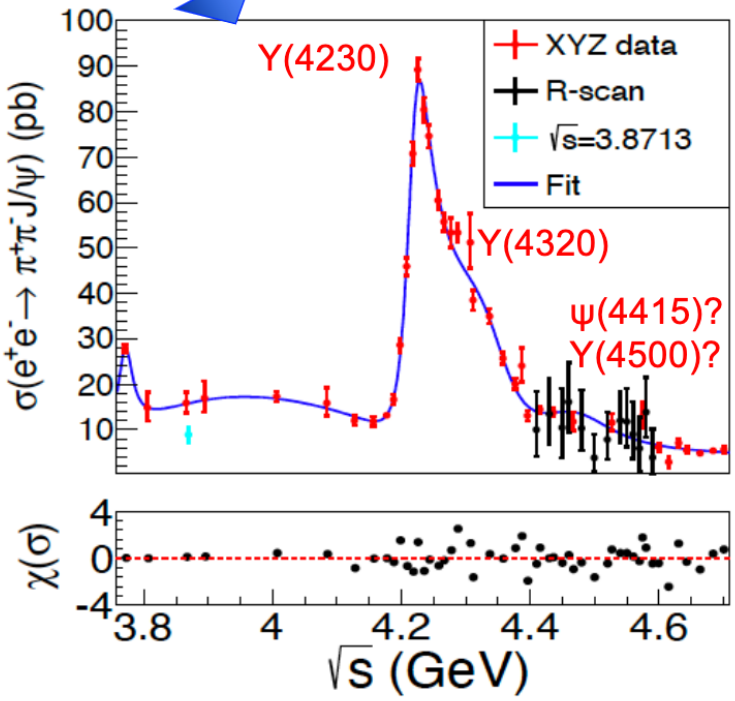


Cross sections of $e^+e^- \to \pi^+\pi^- J/\psi$

arXiv:2206.08554



Higher statistics, higher precision, higher energies, better fit



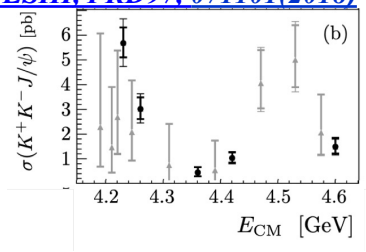
- ✓ Y(4230) and Y(4320) observed with > 10σ
- ✓ Structure around 4 GeV better fit by a BW (before exp)
- ✓ Evidence ~3σ of a structure at higher energies
  ψ(4415)? The new Y(4500)?
- ✓ By including the high energy state in the fit, the Y(4320) parameters change

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

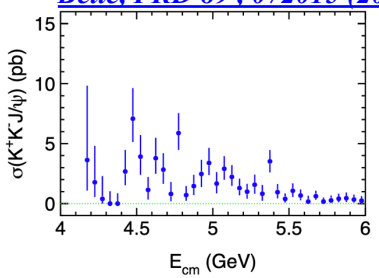
$M_{Y(4320)} = 4298 \pm 12 \pm 26\ \mathrm{MeV}/c^2$
$\Gamma_{Y(4320)} = 127 \pm 17 \pm 10\ \mathrm{MeV}$

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

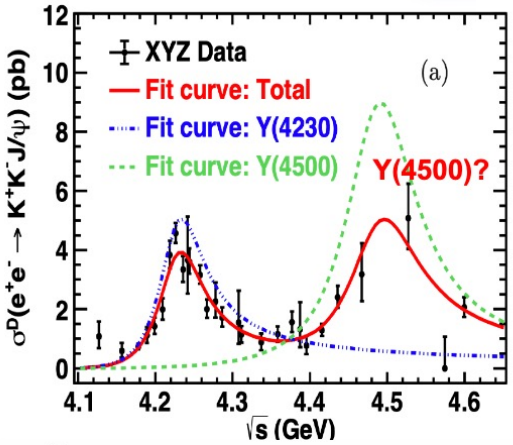
[BESIII, PRD97, 071101(2018)](#)

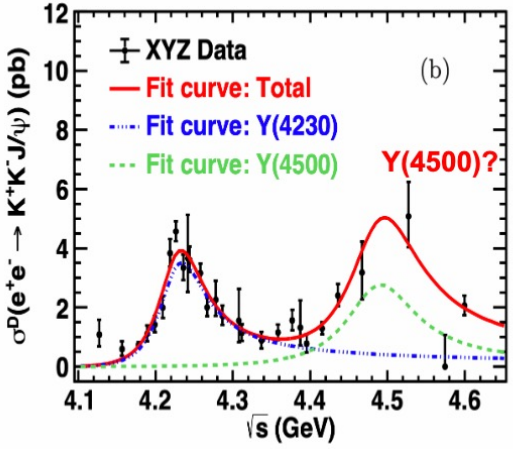


[Belle, PRD 89 , 072015 (2014)](#)



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))

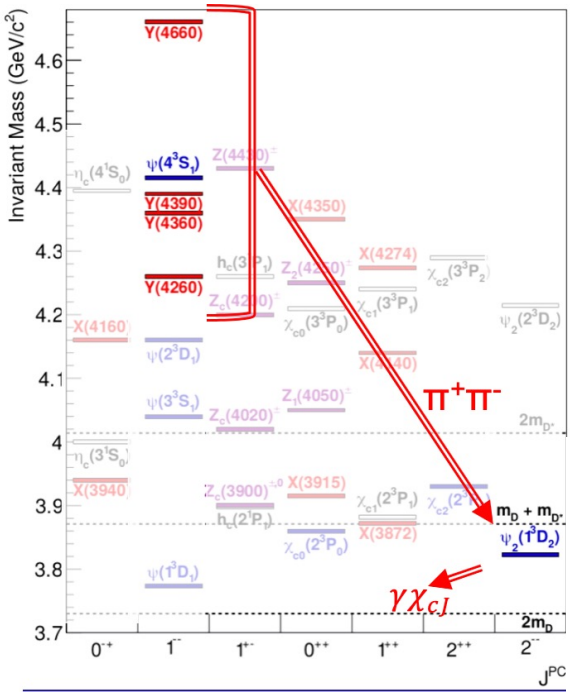
	Parameters	Solution I	Solution II
$Y(4230)$	M(MeV)	$4225.3 \pm 2.3 \pm 21.5$	
	Γ_{tot}(MeV)	$72.9 \pm 6.1 \pm 30.8$	
	$\Gamma_{ee}\mathcal{B}$(eV)	$0.42 \pm 0.04 \pm 0.15$	$0.29 \pm 0.02 \pm 0.10$
$Y(4500)$	M(MeV)	$4484.7 \pm 13.3 \pm 24.1$	
	Γ_{tot}(MeV)	$111.1 \pm 30.1 \pm 15.2$	
	$\Gamma_{ee}\mathcal{B}$(eV)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

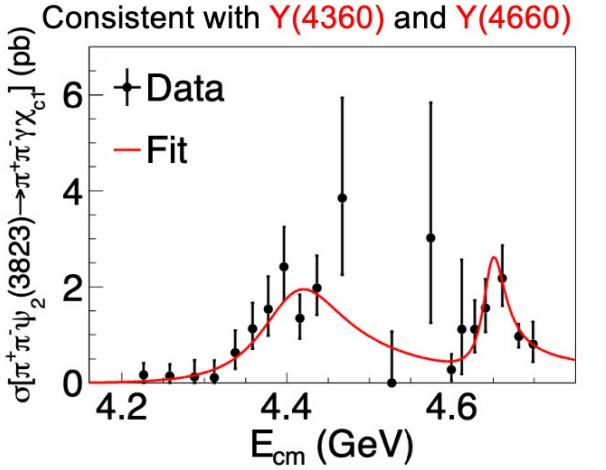
arXiv:2204.07800 submitted to PRL

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

arXiv:2203.05815

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

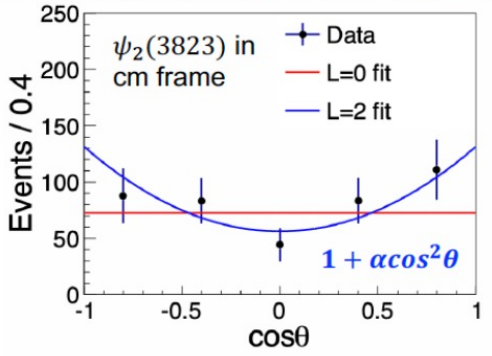


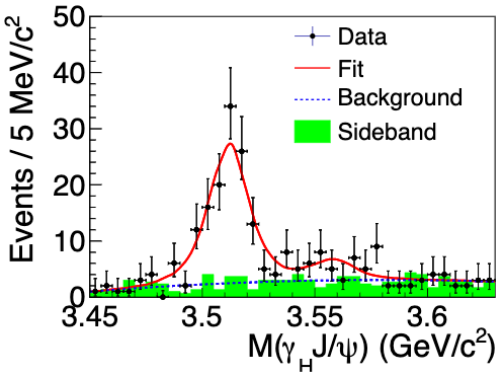


Parameters	Solution I	Solution II
$M[R_1]$	$4406.9 \pm 17.2 \pm 4.5$	
$\Gamma_{\rm tot}[R_1]$	$128.1 \pm 37.2 \pm 2.3$	
$\Gamma_{e^+e^-}\mathcal{B}_1^{R_1}\mathcal{B}_2$	$0.36 \pm 0.10 \pm 0.03$	$0.30 \pm 0.09 \pm 0.03$
$M[R_2]$	$4647.9 \pm 8.6 \pm 0.8$	
$\Gamma_{\rm tot}[R_2]$	$33.1 \pm 18.6 \pm 4.1$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

S-wave $\pi^+\pi^-$, *such as* $f_0(500)$

$L = 2$ slightly favored over $L = 0$





Most precise measurement

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

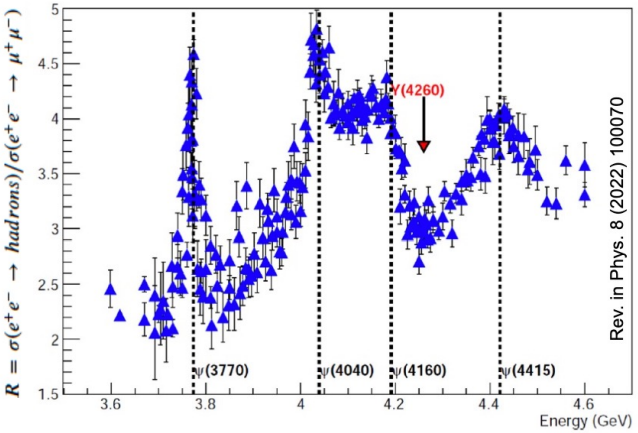
- consistent with Y(4360) and Y(4660)

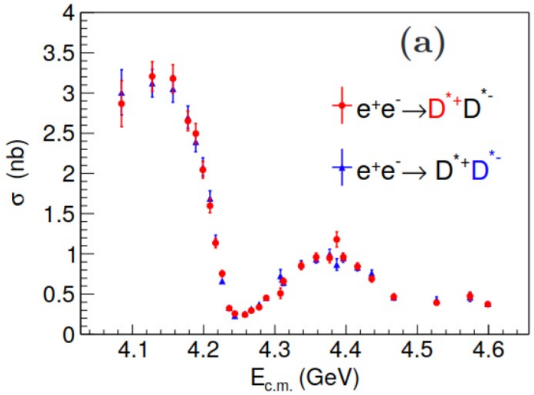
$$\frac{\mathcal{B}[\psi_2(3823)\to\gamma\chi_{c2}]}{\mathcal{B}[\psi_2(3823)\to\gamma\chi_{c1}]} = 0.33 \pm 0.12 (< 0.51))$$

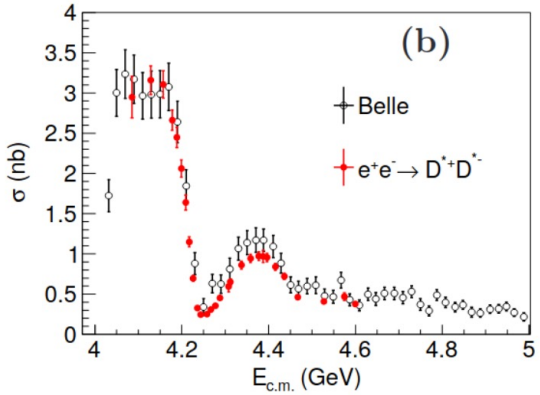
Open charm cross sections

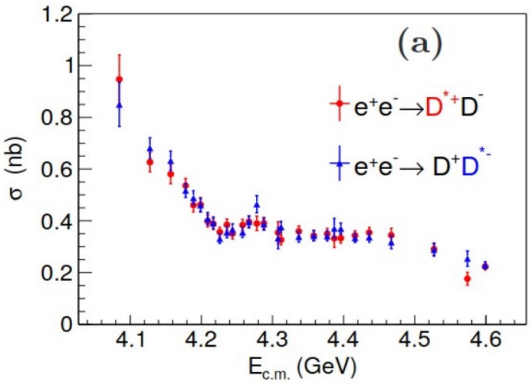
- essential to fully understand the XYZ states
- Important input for coupled-channel analysis

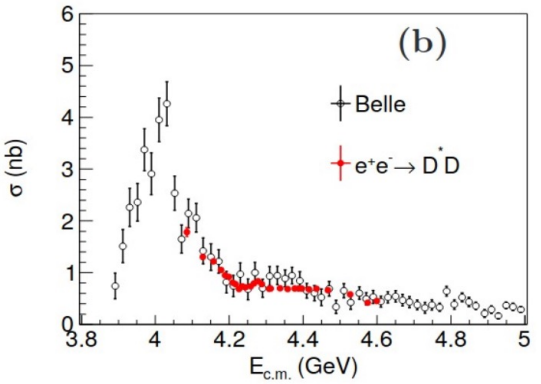
JHEP2022, 55 (2022)





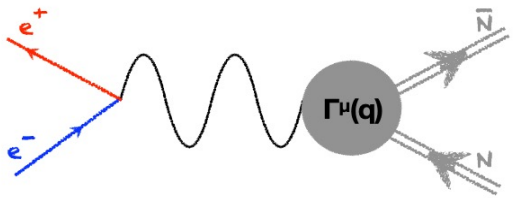


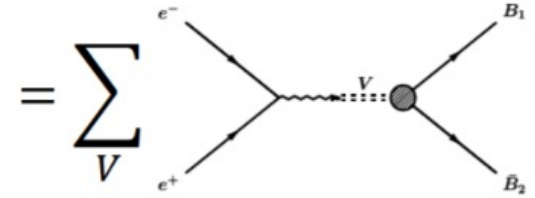


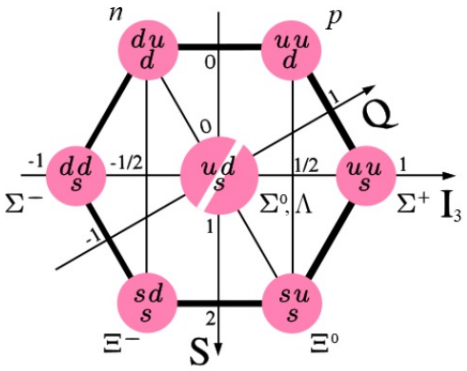


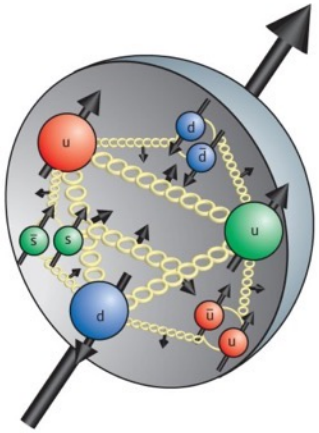
- Good agreement with existing measurements, with best precisions
- Structure at 4.39 GeV in D^*D^*?

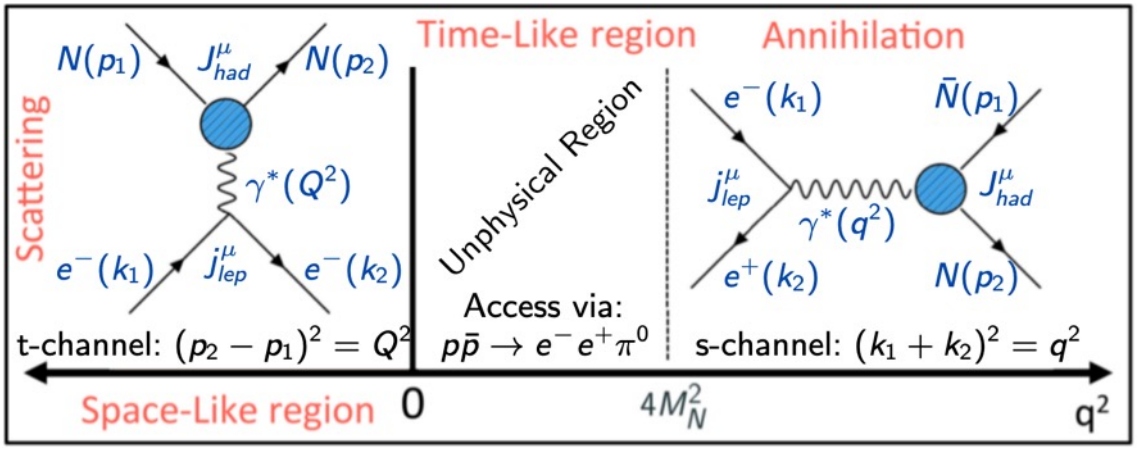
Form factors of baryons









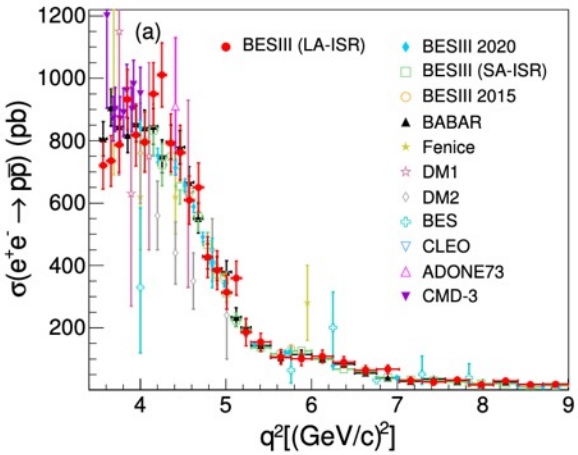


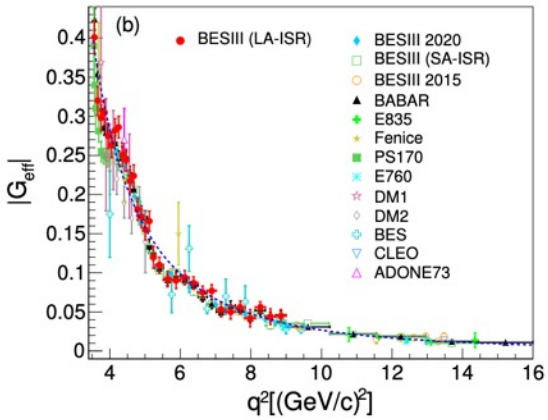
In the time-like region, access to the Electromagnetic Form Factors (EFF) of the baryons, which characterize the internal structure of the baryon

Threshold production of the proton

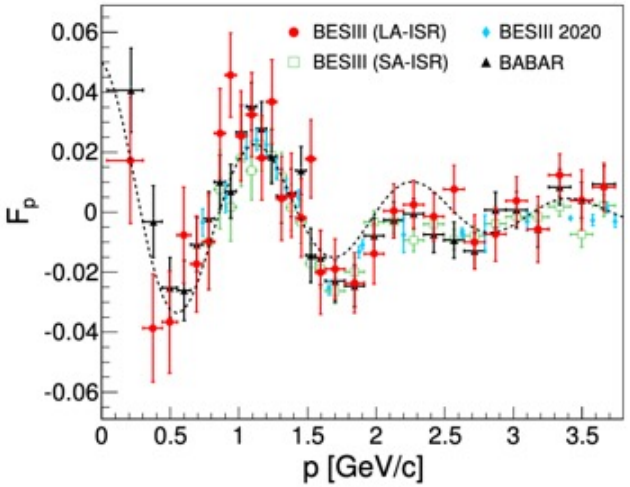
$$\frac{d\sigma_{p\bar{p}}(s)}{d\Omega} = \frac{\alpha^2\beta C}{4s}\left[|G_M(s)|^2(1+\cos^2\theta) + \frac{4m_p^2}{s}|G_E(s)|^2\sin^2\theta\right]$$

BESIII tagged ISR: PLB 817, 136328 (2021)
BESIII 2020 energy scan: PRL124, 042001 (2020)
BESIII untagged ISR: PRD99, 092002 (2019)
BESIII 2015 energy scan: PRD91, 112004(2015)





$$|G_{\rm eff}| = \sqrt{\frac{2\tau|G_{\rm M}|^2 + |G_{\rm E}|^2}{2\tau+1}}$$

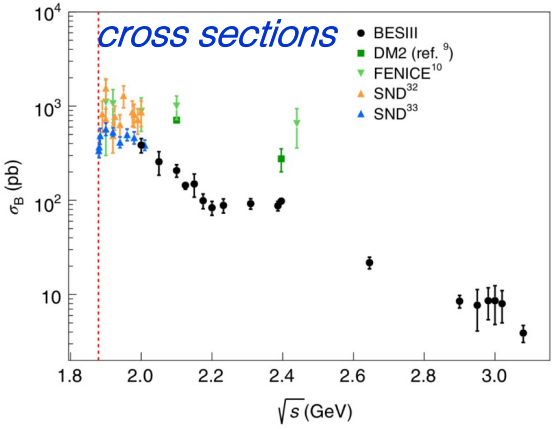


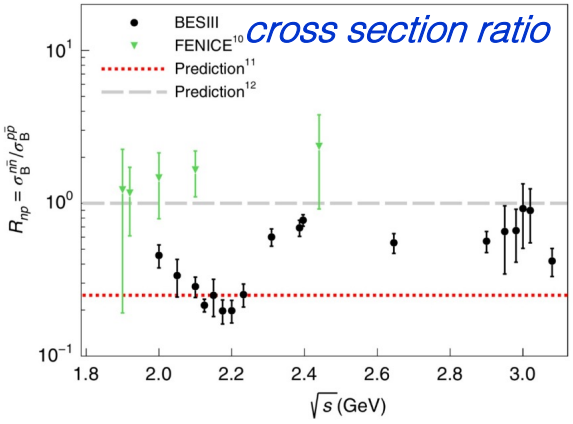
- BESIII provides best precisions: cross section threshold enhancement established
- Oscillating structures observed in the EFF after subtracted the modified dipole parameterization
  [PRL**114**, 232301 (2015)]
  - confirming the observation at BaBar

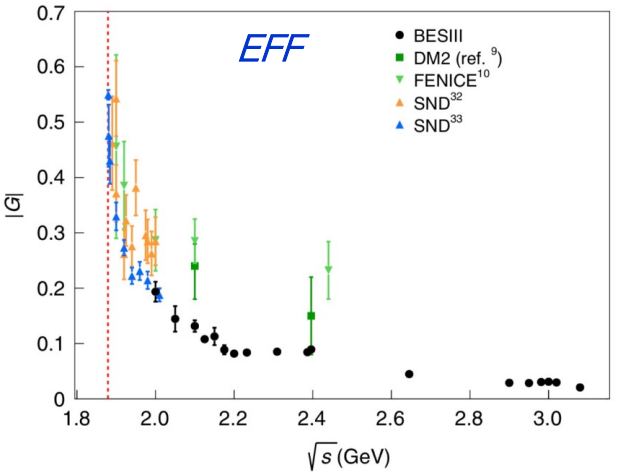
Threshold production of $e^+e^- \to n\bar{n}$

- Very challenging measurement due to pure neutron final states
- BESIII takes three approaches and provide validations among each other

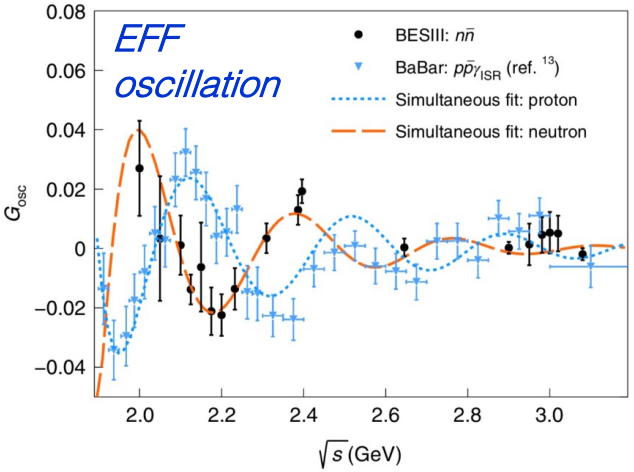
Nature Physics 17, 1200 (2021)



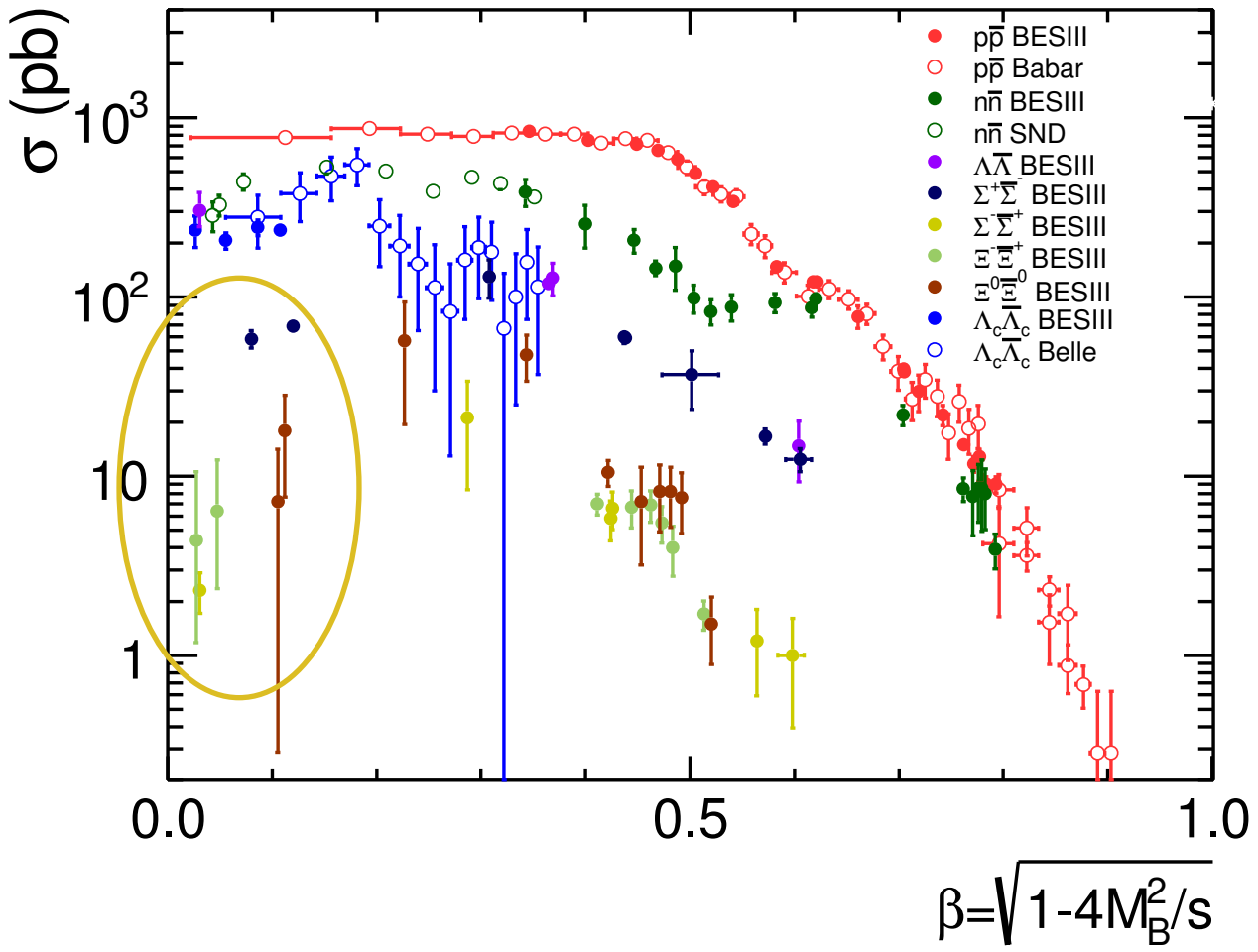




- XS measured in a wide range with unprecedented precision (~10%): confirming threshold enhancement
- XS ratio between proton and neutron: do not support the FENICE conjecture, but are within the theoretical predictions
- Oscillation of EFF observed in neutron data: simultaneous fit of proton and neutron data gives shared frequency (5.55±0.28) GeV^{-1} with almost orthogonal phase difference of (125±12)^{O}



Comparisons of different baryon pairs



Threshold enhancement is observed for nucleon/Λ/Λ_c pairs, while not for Σ/Ξ pairs

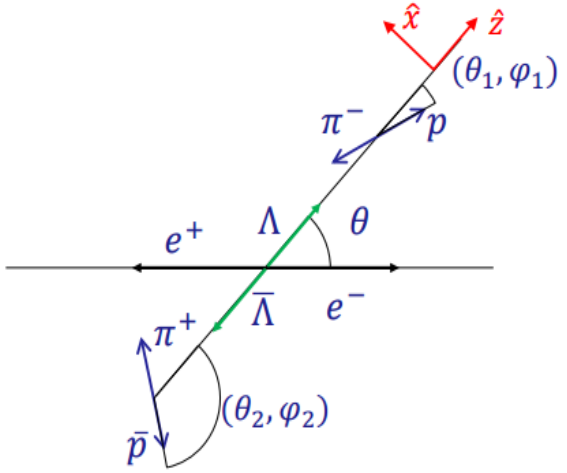
Relative phase of Λ Form Factors(FFs)

- Through the weak decay of hyperons, we could probe its polarization. Hence more information of the EFF can be studied
- $\Delta\phi$ is the phase angle difference of G_E and G_M: can be explored via angular analysis of the spin-coherent hyperon-pair weak decays

Unpolarized part Polarized part Spin correlated part

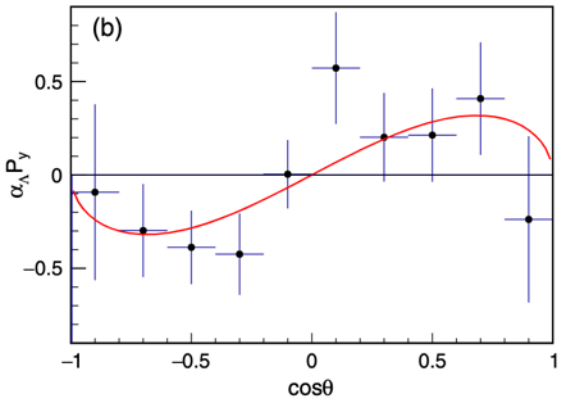
$$W(\xi) = F_0(\xi) + \eta F_5(\xi) + \alpha\bar{\alpha}\,(F_1(\xi) + \sqrt{1-\eta^2}\cos(\Delta\Phi)\,F_2(\xi) + \eta F_6(\xi)) + \sqrt{1-\eta^2}\sin(\Delta\Phi)(\alpha F_3(\xi) + \bar{\alpha}F_4(\xi))$$

$$R = |G_E/G_M|,\ \Delta\Phi = \Phi_E - \Phi_M,\ \eta = \frac{\tau - R^2}{\tau + R^2}$$



- First complete EFF measurement of the Λ at 2.396 GeV

PRL123,122003 (2019)



$$\left|\frac{G_E}{G_M}\right| = 0.96 \pm 0.14(\text{stat.}) \pm 0.02(\text{sys.})$$

$$\Delta\Phi = 37^\circ \pm 12^\circ(\text{stat.}) \pm 6^\circ(\text{sys.})$$

Confirm the complex form of EMFFs !

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

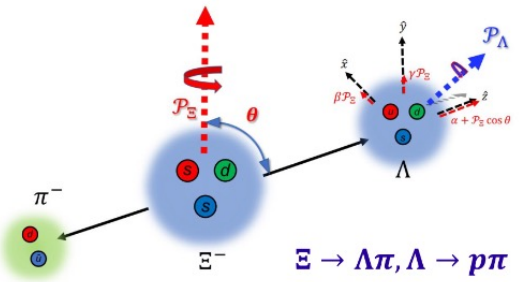
$$S = |S|\exp(i\xi_S)\exp(i\delta_S)$$
$$P = |P|\exp(i\xi_P)\exp(i\delta_P)$$

Weak CP-odd phases

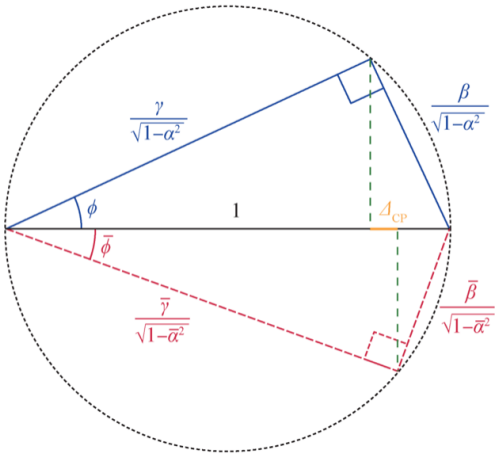
Two Measureable Parameters

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

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]:

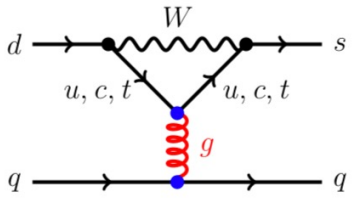
$-3\times10^{-5} \leq A_\Lambda \leq 4\times10^{-5}$

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

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]:

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



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

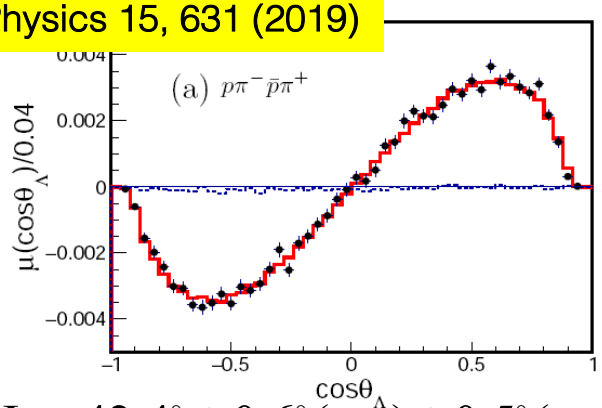
$0.5 < B_G < 2$ and $0.2 < |\kappa| < 1$ [3]

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

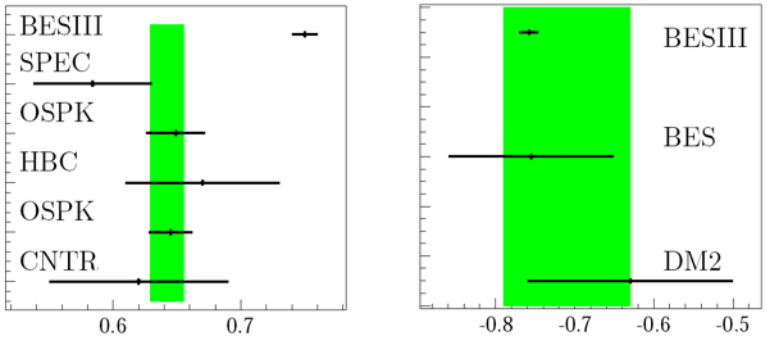
Hyperons produced at ψ peaks

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

Nature Physics 15, 631 (2019)



$\Delta\Phi = 42.4^\circ \pm 0.6^\circ(sta) \pm 0.5^\circ(sys.)$

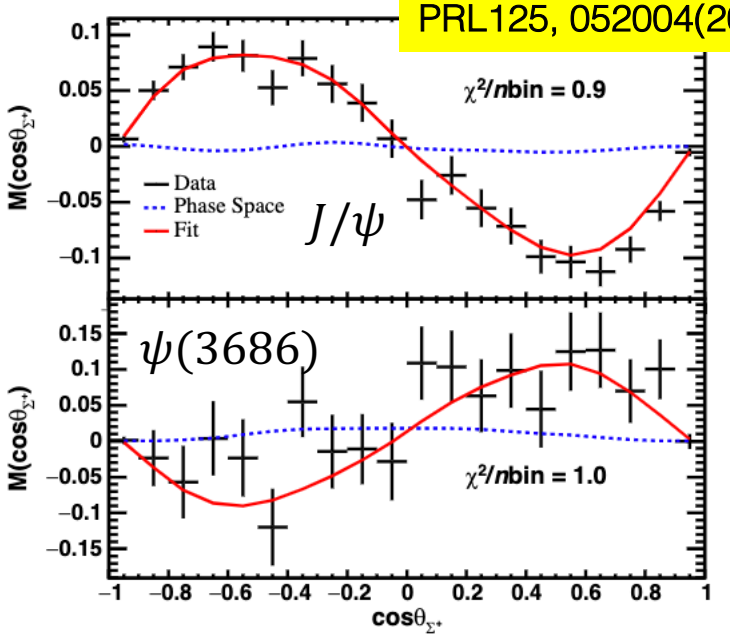


(a) α_- for $\Lambda \to p\pi^-$ (b) α_+ for $\bar{\Lambda} \to \bar{p}\pi^+$

- Very precise determination of hyperon decay asymmetry: ➔ CPV search
- Correct a long-history underestimation of Λ decay asymmetry

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

PRL125, 052004(2020)



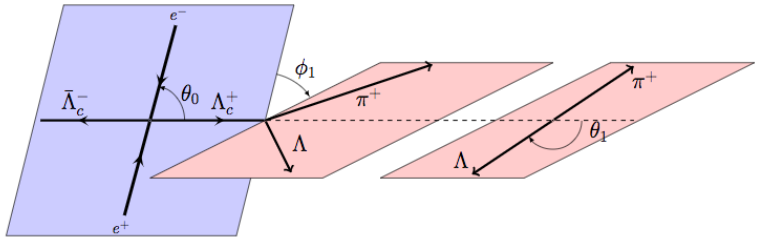
Parameter	Measured value
$\alpha_{J/\psi}$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.270 \pm 0.012 \pm 0.009$
$\alpha_{\psi'}$	$0.682 \pm 0.03 \pm 0.011$
$\Delta\Phi_{\psi'}$	$0.379 \pm 0.07 \pm 0.014$
α_0	$-0.998 \pm 0.037 \pm 0.009$
$\bar{\alpha}_0$	$0.990 \pm 0.037 \pm 0.011$

Λ_c polarization and decay asymmetries

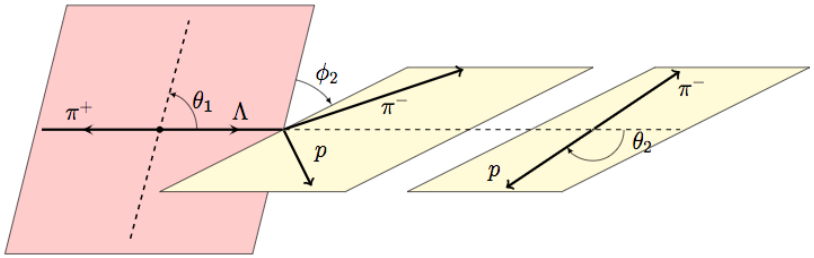
single tag method

PRD100, 072004 (2019)

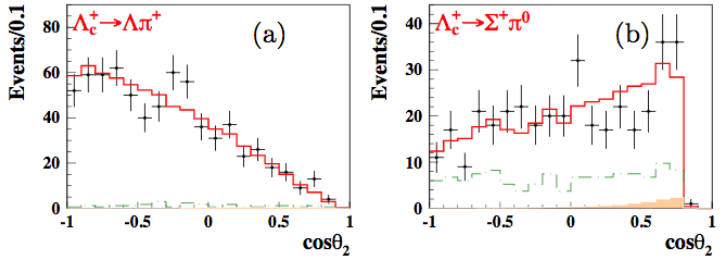
4(6)-fold angular analysis of the cascade decays of $\Lambda_c \to pK_s, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$ based on 567/pb data

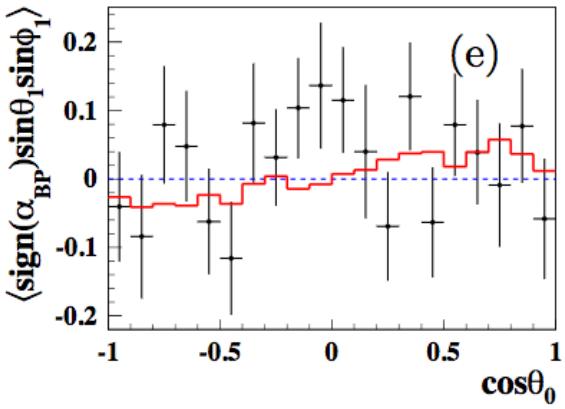


CM frame $\quad$ Λ_c^+ rest frame



Λ_c^+ rest frame $\quad$ Λ rest frame





$\sin\Delta\phi = -0.28 \pm 0.13 \pm 0.03$

$\Lambda_c^+ \to$		pK_S^0	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
$\alpha_{BP}^{\Lambda_c^+}$	Predicted	−1.0 [16], 0.51 [11] −0.49 [10], −0.90 [10] −0.49 [17], −0.97 [18] −0.66 [19], −0.90 [30] −0.99 [20], −0.91 [31]	−0.70 [16], −0.67 [11] −0.95 [10], −0.99 [10] −0.96 [17], −0.95 [18] −0.99 [19], −0.86 [30] −0.99 [20], −0.94 [31]	0.71 [16], 0.92 [11] 0.79 [10] −0.49 [10] 0.83 [17], 0.43 [18] 0.39 [19], −0.76 [30] −0.31 [20], −0.47 [31]	0.70 [16], 0.92 [11] 0.78 [10], −0.49 [10] 0.83 [17], 0.43 [18] 0.39 [19], −0.76 [30] −0.31 [20], −0.47 [31]
	PDG [2]		-0.91 ± 0.15	-0.45 ± 0.32	
	This work	$0.18 \pm 0.43 \pm 0.14$	$-0.80 \pm 0.11 \pm 0.02$	$-0.57 \pm 0.10 \pm 0.07$	$-0.73 \pm 0.17 \pm 0.07$

- Best precisions on the hadronic weak decay asymmetries
- The transverse polarization is firstly studied and found to be non-zero with 2.1σ

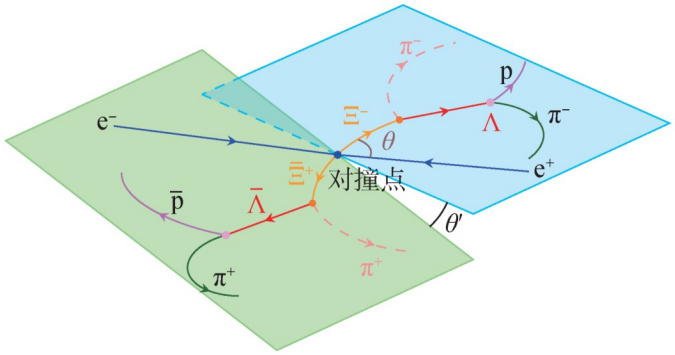
CPV in $\Xi^- \to \Lambda\pi^-$ decay

Nature 606, 64 (2022)

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

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
$<\phi_\Xi>$	$0.016 \pm 0.014 \pm 0.007$ 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!

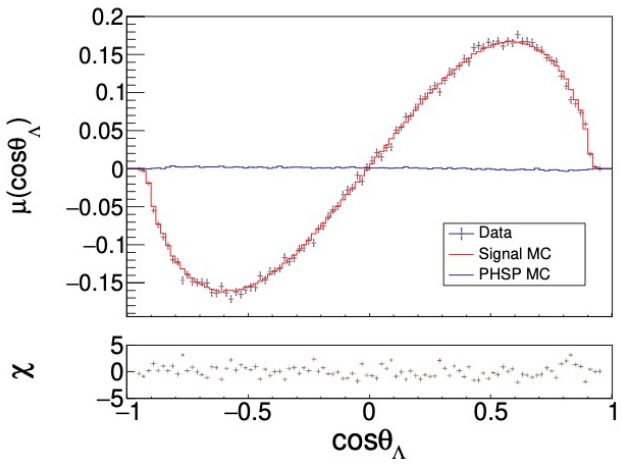
HyperCP: $\phi_{\Xi,HyperCP} = -0.042 \pm 0.011 \pm 0.011$
BESIII: $<\phi_\Xi> = 0.016 \pm 0.014 \pm 0.007$

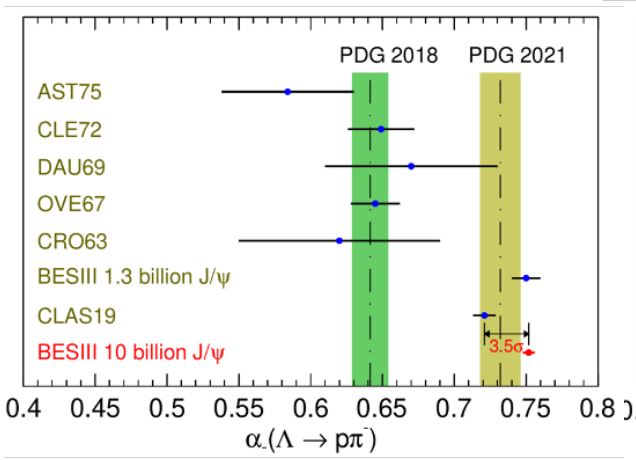
HyperCP: PRL 93(2004) 011802

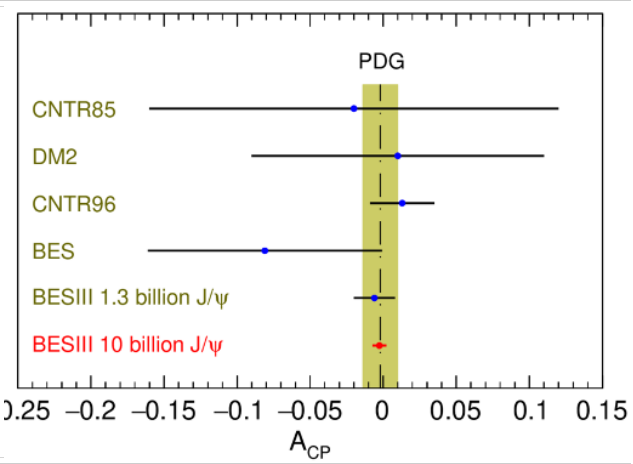
Update on $J/\psi \to \Lambda\bar{\Lambda}$

arXiv:2204.11058

- 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%





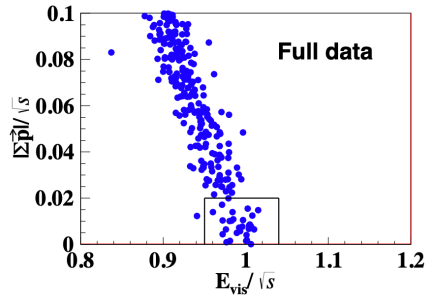


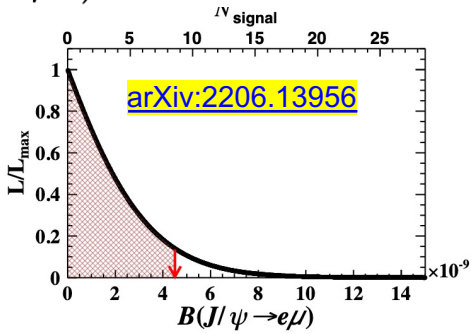
Par.	This Work*	Previous results **	PDG 2018 ***
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0024$	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0080$	$0.740 \pm 0.010 \pm 0.009$	-
α_-	$0.7519 \pm 0.0036 \pm 0.0019$	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013
α_+	$-0.7559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

Rare processes

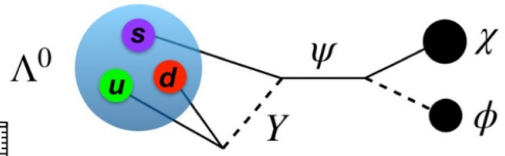
LFV in $J/\psi \to e^+\mu^-$

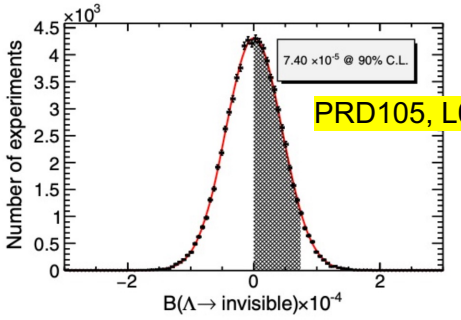
$$\mathcal{B}(J/\psi \to e^{\pm}\mu^{\mp}) < 4.5 \times 10^{-9}$$



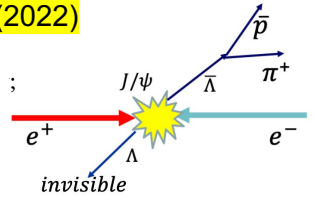


Λ invisible decays



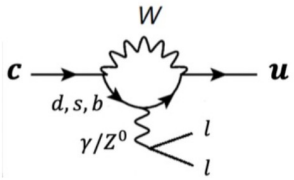


PRD105, L071101(2022)

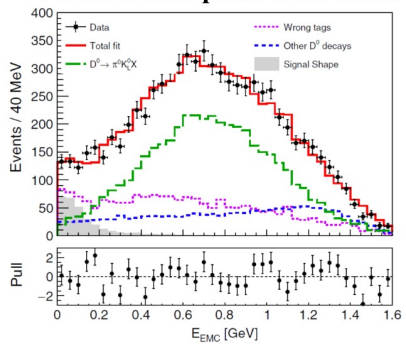


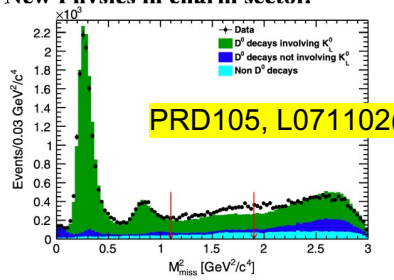
$$\mathcal{B}(\Lambda \to invisible) < 7.4\times10^{-5}$$

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



- $\mathcal{B}(D^0 \to \pi^0\nu\bar{\nu}) < 2.1\times10^{-8}$
- 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.



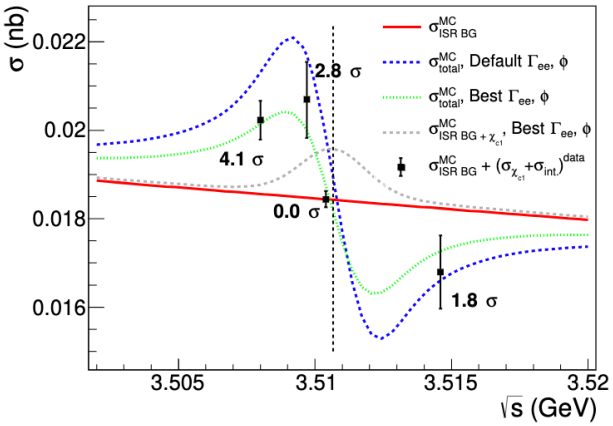


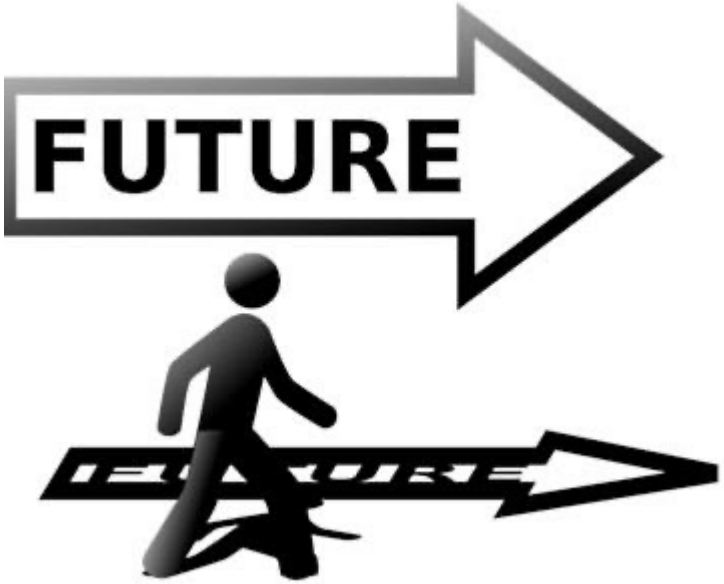
PRD105, L071102(2022)

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

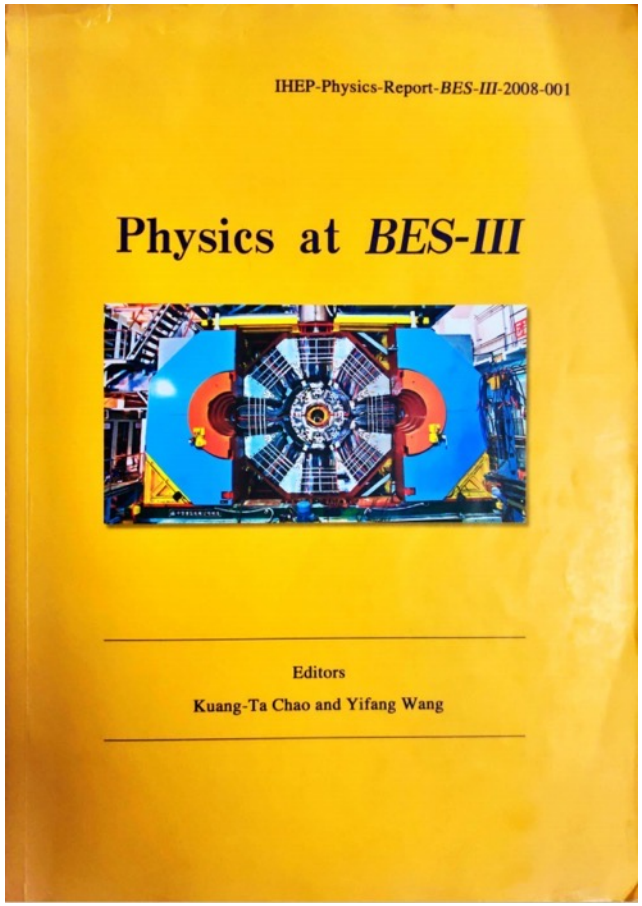
$$\Gamma_{ee} = (0.12^{+0.13}_{-0.08})\ \text{eV}.$$

arXiv:2203.13782




FUTURE

BESIII Physics



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

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	$\Sigma_c\bar{\Sigma}_c$ 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

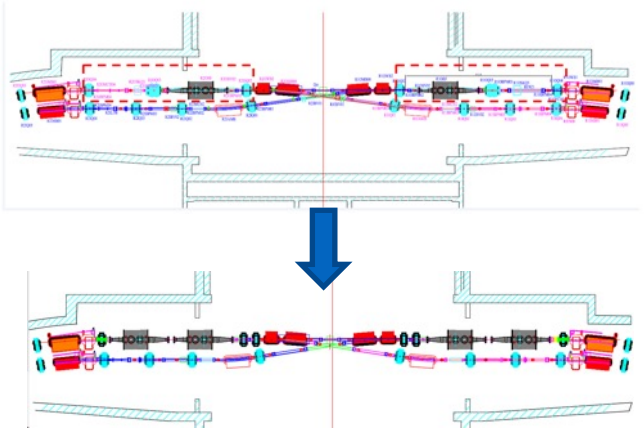
to be complete in 2022-23

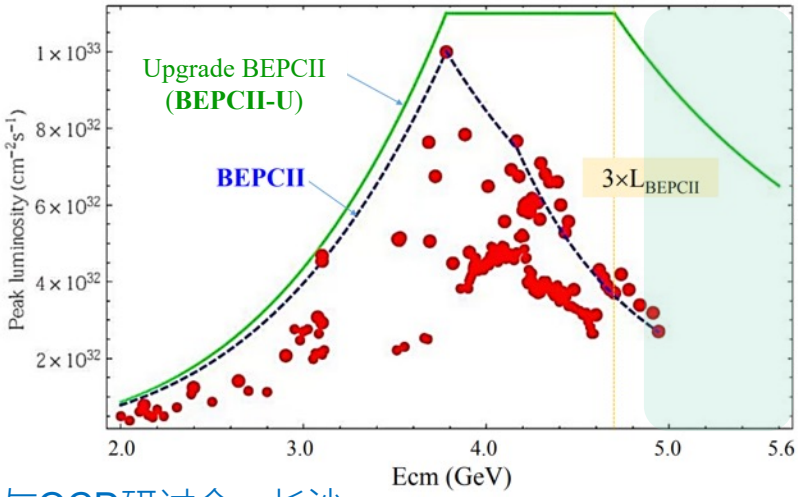
~55 fb^{-1}

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

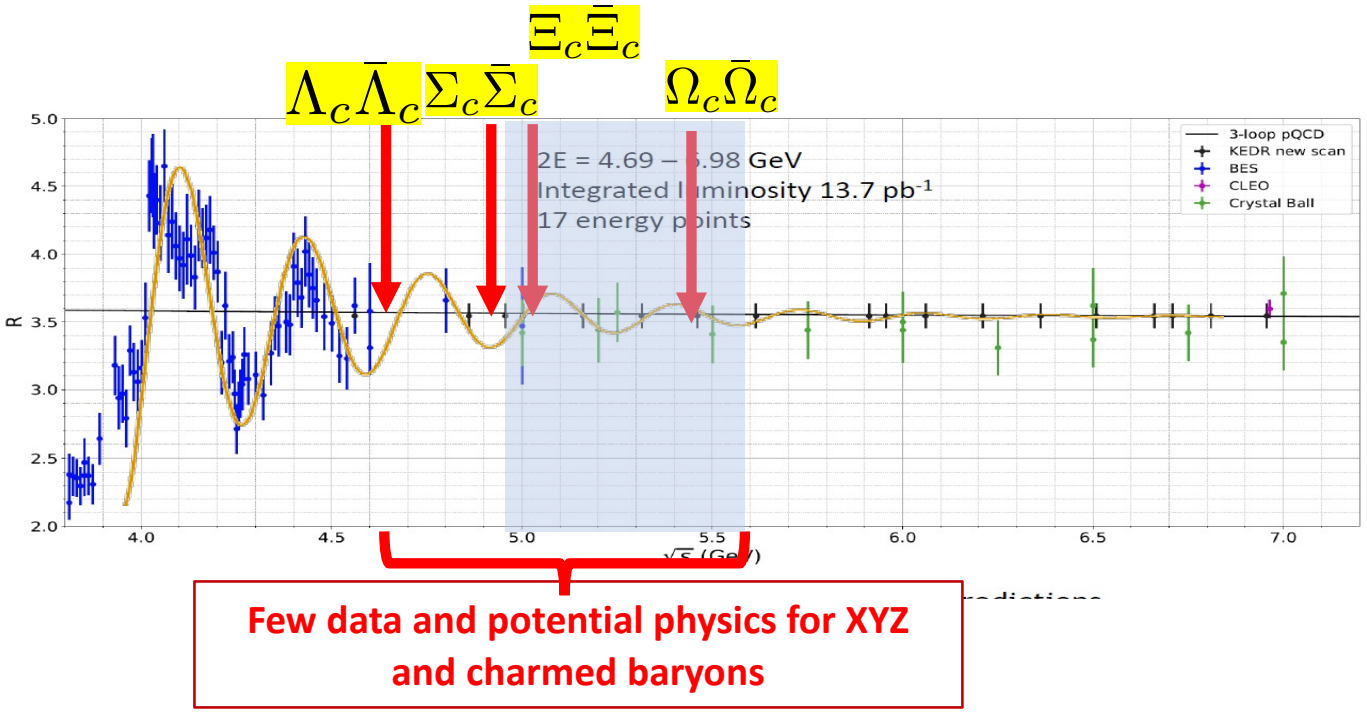
	BEPCII	BEPCII-U
Lum [10^{32}cm^{-2}s^{-1}]	3.5	11
β_y^* [cm]	1.5	1.35
Bunch Current [mA]	7.1	7.5
Bunch Num	56	120
SR Power [kW]	110	250
$\xi_{y,\mathrm{lum}}$	0.029	0.033
Emittance [nmrad]	147	152
Coupling [%]	0.53	0.35
Bucket Height	0.0069	0.011
$\sigma_{z,0}$ [cm]	1.54	1.07
σ_z [cm]	1.69	1.22
RF Voltage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



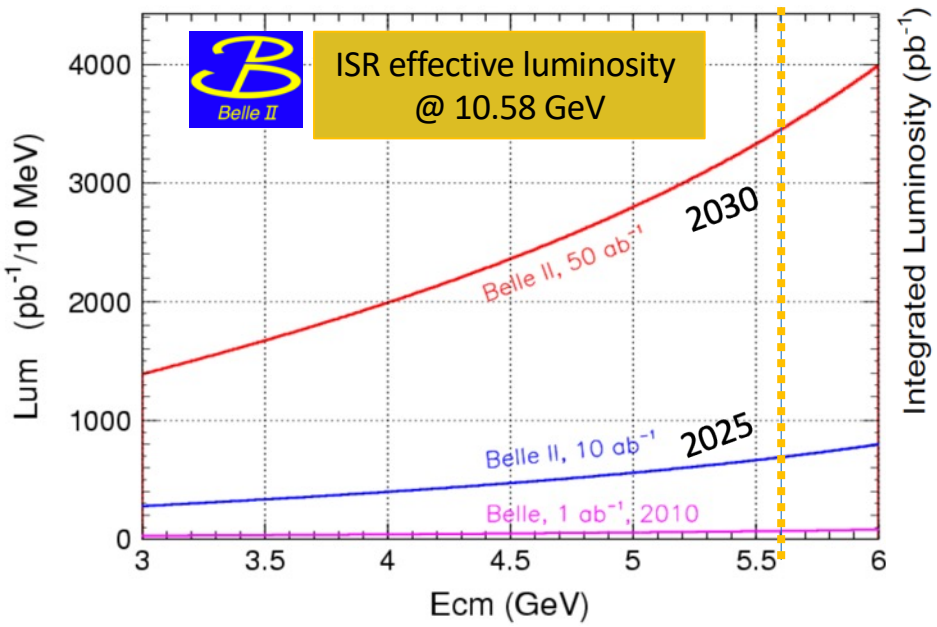


Potential physics with BEPCII-U

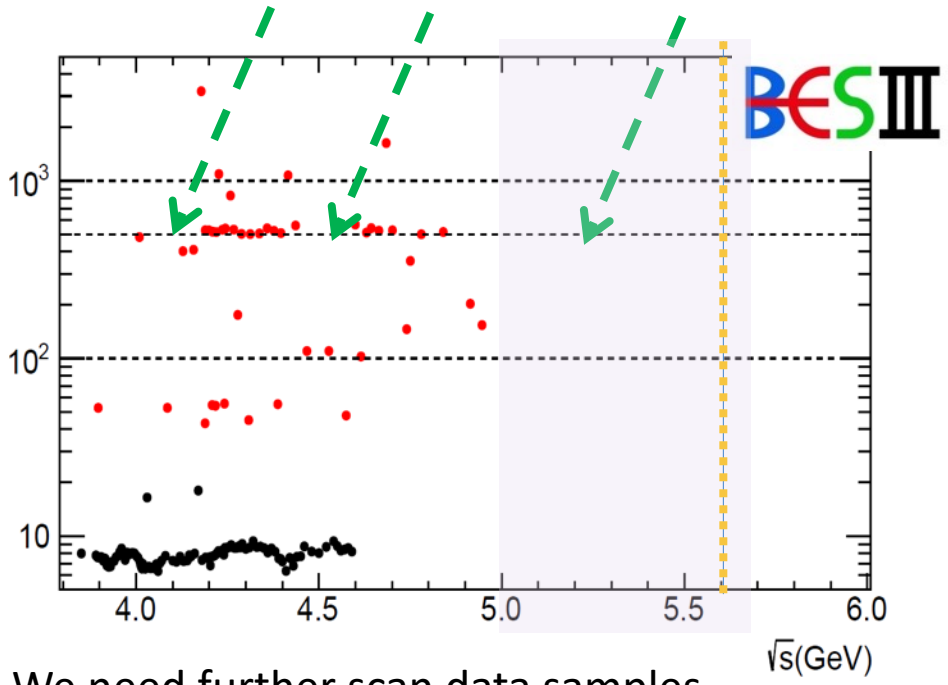
- ✓ Detailed studies of the known $Z_{c(s)}$ states and search for `black swans` in the higher energy region within a considerable amount of data sets.
- ✓ Cover all the ground-state charmed baryons: production & decays, CPV search



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: $\Omega_c^0\bar{\Omega}_c^0$

Joint efforts among experiments and theories

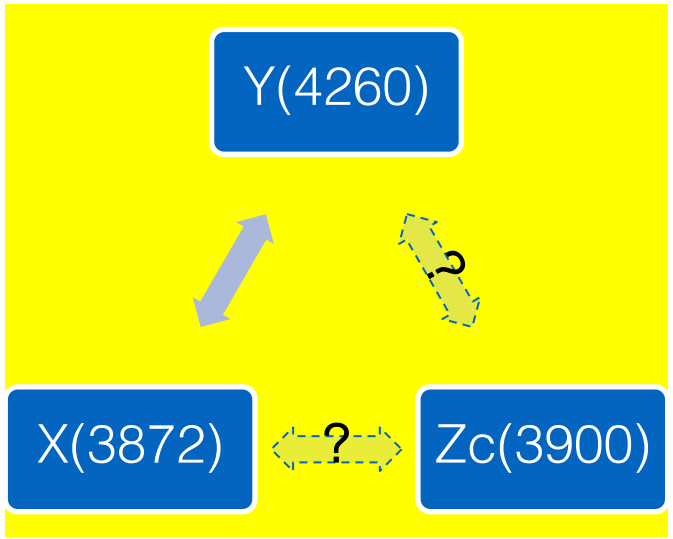
- It is crucial that different experiments, such as BESIII, LHCb and Belle II, exchange information in the efforts of amplitude analyses
  - ✓ Sharing the knowledge on analysis tools
    eg, **TF-PWA** (talks given inside BESIII and LHCb) https://github.com/jiangyi15/tf-pwa
  - ✓ Constraints on properties 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
$Z_c(3900)^{\pm,0}$	$\pi^{\mp}J/\psi$, $(D^*\bar{D})^{\mp}$	BESIII, Belle CLEO
$Z_c(4020)^{\pm,0}$	$\pi^{\mp}h_c$, $(D^*\bar{D}^*)^{\mp}$	BESIII
$Z_c(4430)^{\pm}$	$\pi^{\mp}\psi(2S)$ $\pi^{\pm}J/\psi$	Belle, ~~BaBar,~~ LHCb

in $e^+e^- \to \pi^- Zc$

in $e^+e^- \to \pi^- Zc$

in $B \to KZc$



- Energy-dependence
- Patterns in productions and decays

Pole properties

World-wide experimental efforts

Models

LQCD

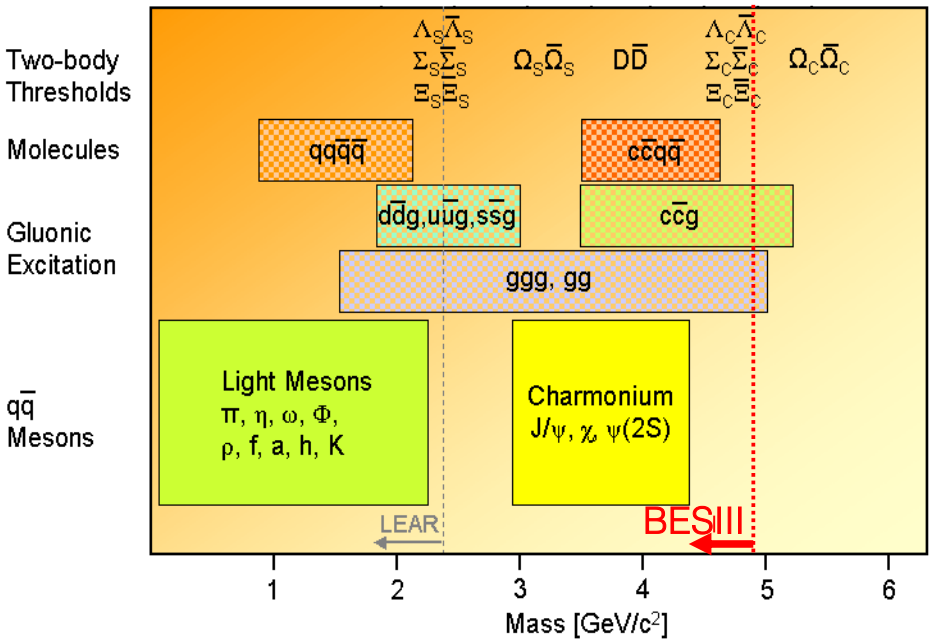
Summary

- 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!

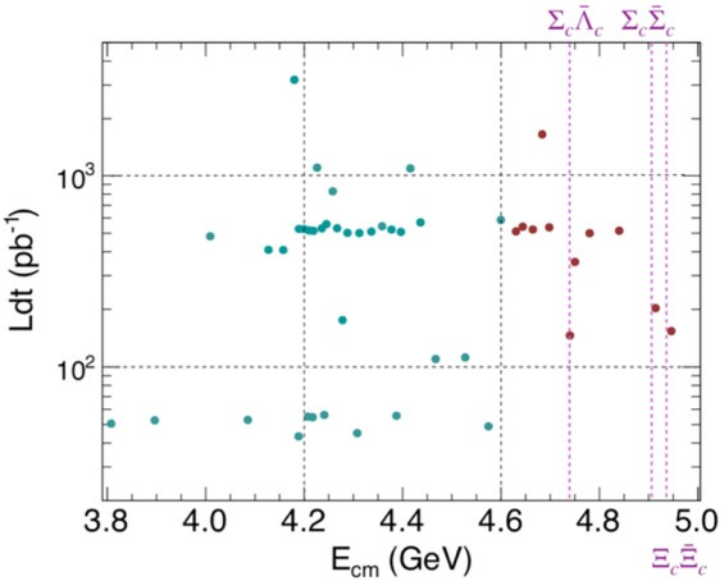
谢谢！

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

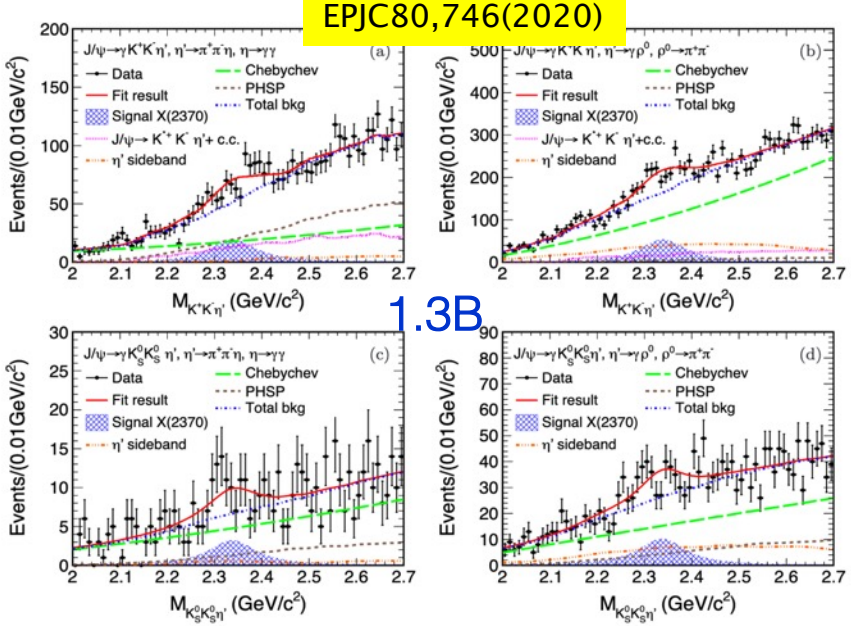
At BESIII, two golden measures to study hadron spectroscopy, *esp.*, to search for exotics

- 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**)

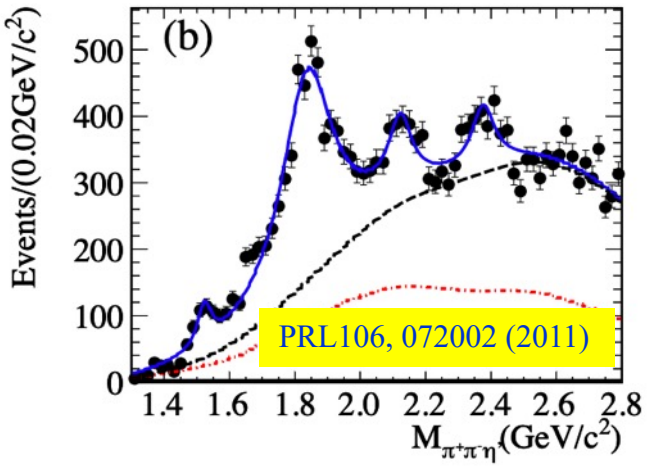
The X(2120) and X(2370)

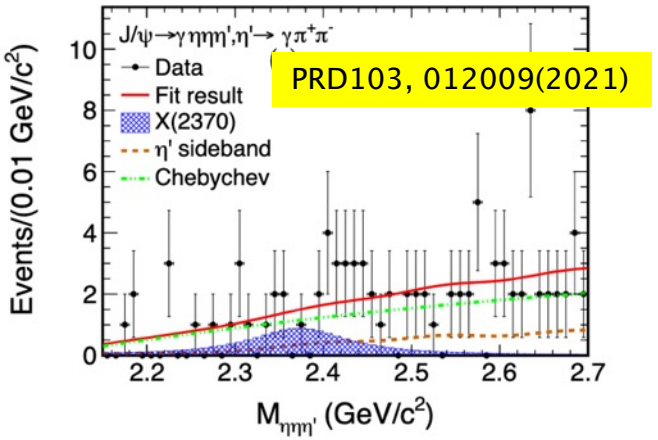
- Observed in $J/\psi \to \gamma\eta'\pi^+\pi^-$ at BESIII [PRL106, 072002 (2011)][PRL117, 042002(2016)]
- Candidates of glueball states
- Combined analysis of $J/\psi \to \gamma K^+K^-\eta'$ and $\gamma K_S K_S \eta'$
- Search for X(2370) in $J/\psi \to \gamma\eta\eta\eta'$

EPJC80,746(2020)



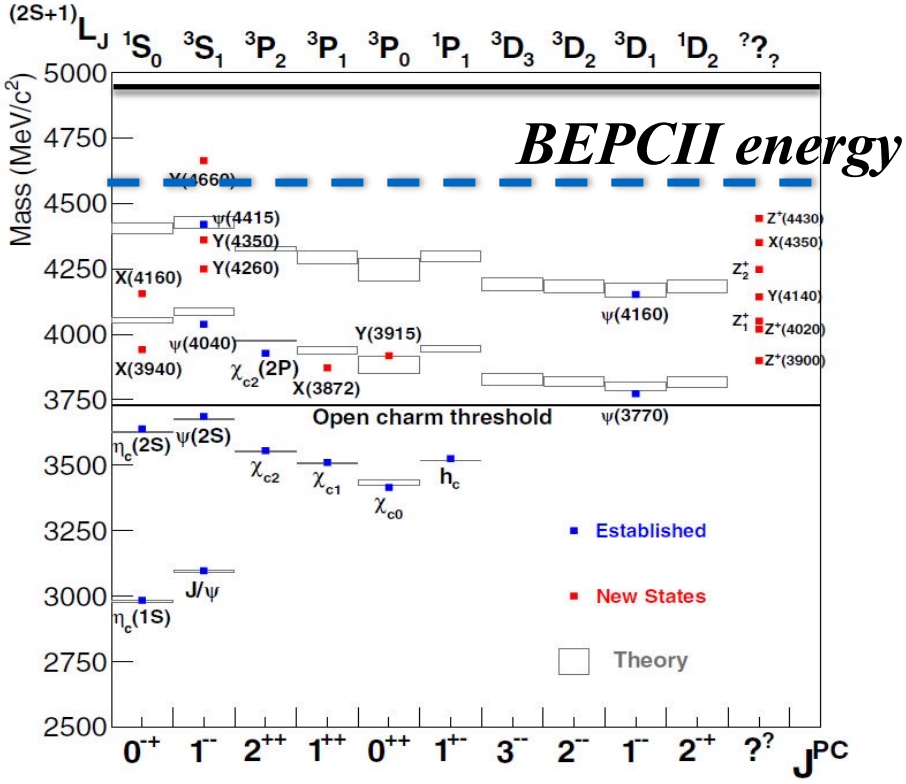
$$M_{X(2370)} = 2341.6 \pm 6.5(\text{stat.}) \pm 5.7(\text{syst.})\ \text{MeV}/c^2,$$
$$\Gamma_{X(2370)} = 117 \pm 10(\text{stat.}) \pm 8(\text{syst.})\ \text{MeV},$$



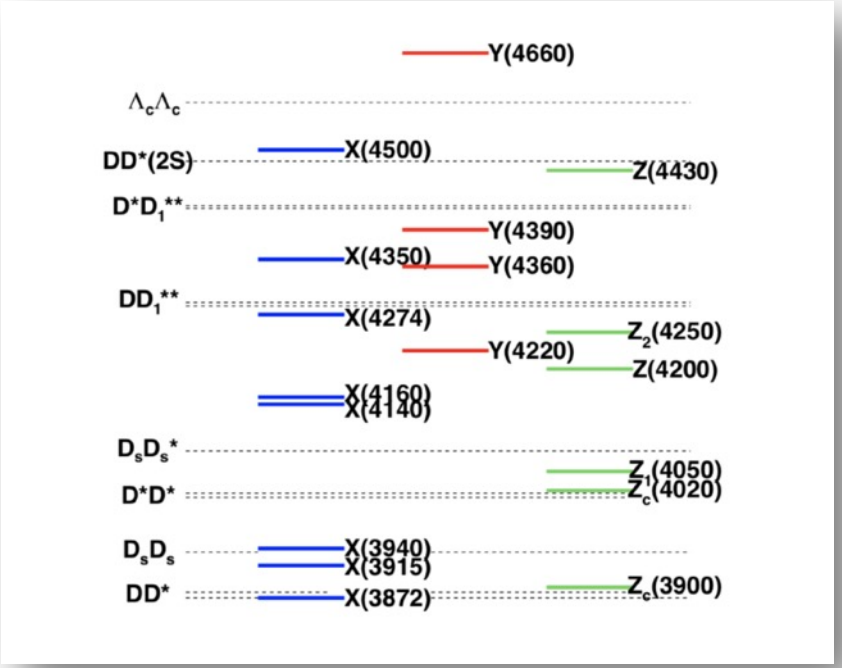


- Observation of $X(2370) \to K\bar{K}\eta'$ with stat. significance of 8.3σ
- No evidence of $X(2120) \to K\bar{K}\eta'$
- No evidence of $X(2370) \to \eta\eta\eta'$

Overpopulated charmonium spectrum



arXiv:1511.01589, arXiv:1812.10947

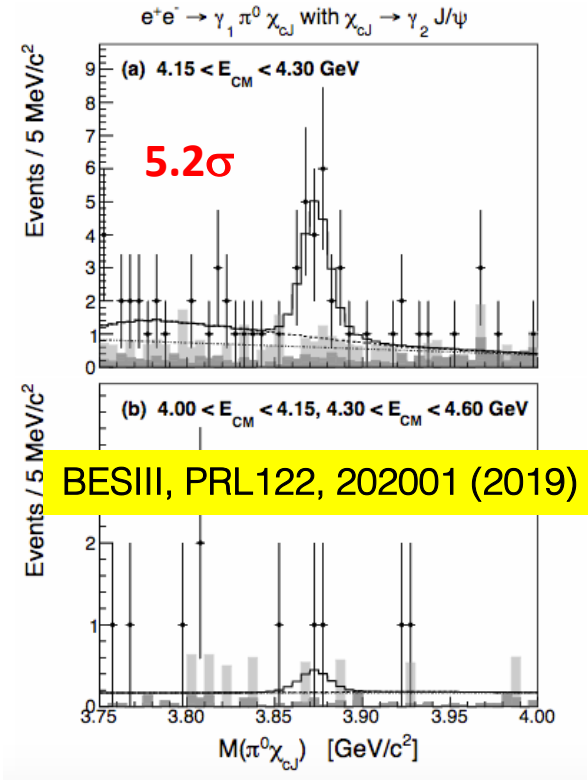


Overpopulated observed new charmonium-like states, i.e. "XYZ":

- Most of them are close to the mass thresholds of charmed meson pairs
- Some are not accommodated as conventional meson
  ==> candidate of exotic hadron states
- More efforts are needed to pin down their nature

More X(3872) decay information

- Observation of X(3872) →$\pi^0\chi_{c1}$



BESIII, PRL122, 202001 (2019)

- Observation of X(3872) → ωJ/ψ

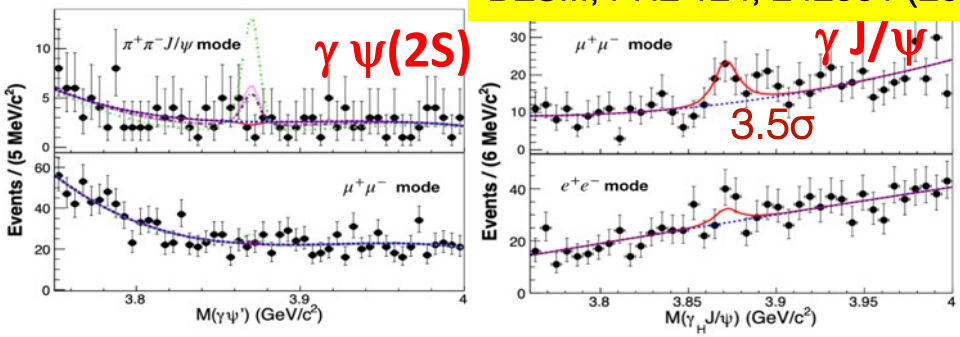
BESIII, PRL 122, 232002 (2019)

- Observation of X(3872) →$D^0\bar{D}^{*0}$

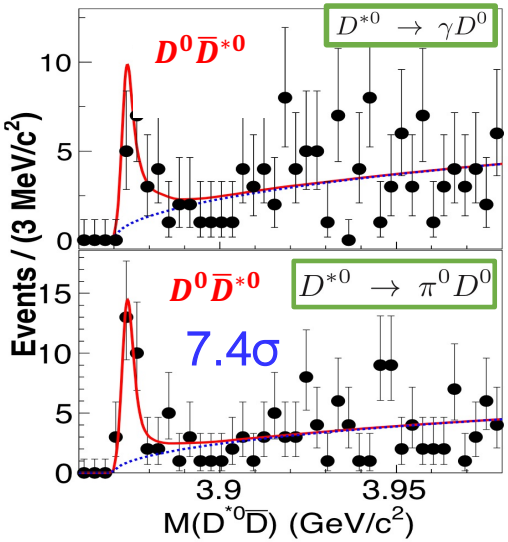
BESIII, PRL 124, 242001 (2020)

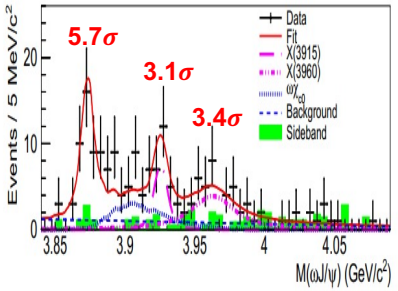
- Transition of $X(3872) \to \gamma$J/ψ, γψ(2S)

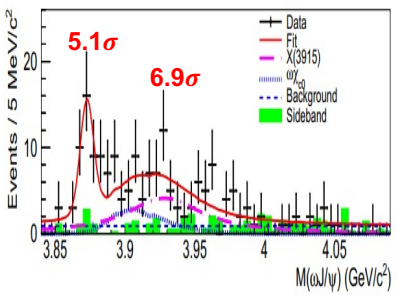
BESIII, PRL 124, 242001 (2020)



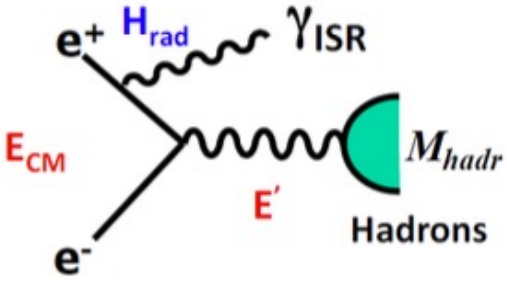
$$R=\frac{BF(X(3872)\to\gamma\psi(2S))}{BF(X(3872)\to\gamma J/\psi)}<0.59 \text{ at } 90\% \text{ C.L.}$$, agrees with Belle(<2.1), while challenges Babar(3.4±1.1) and LHCb results (2.46± 0.70)



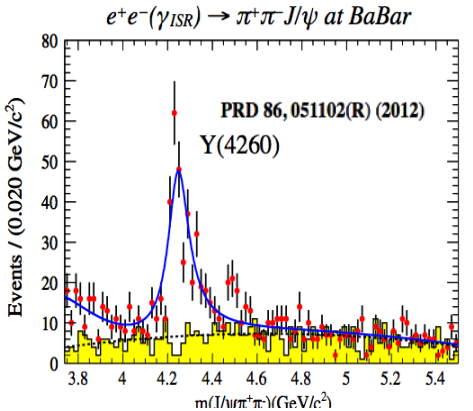


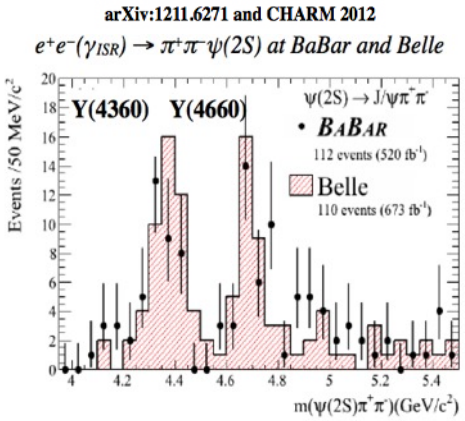


The Y states



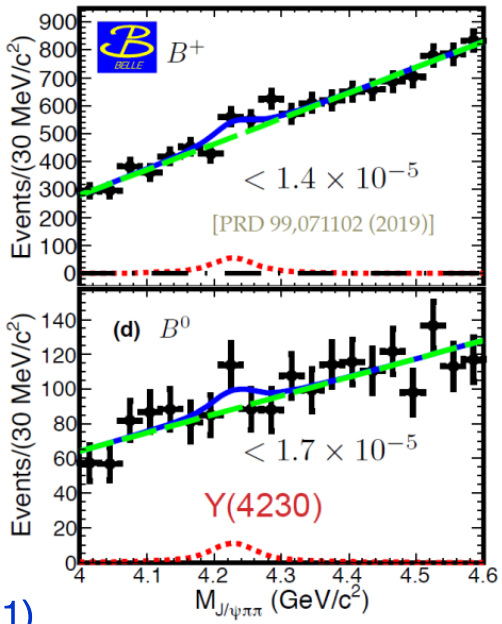
Y states: charmonium-like states with $J^{PC}=1^{--}$; Observed in direct e+e- annihilation or initial state radiation (ISR).



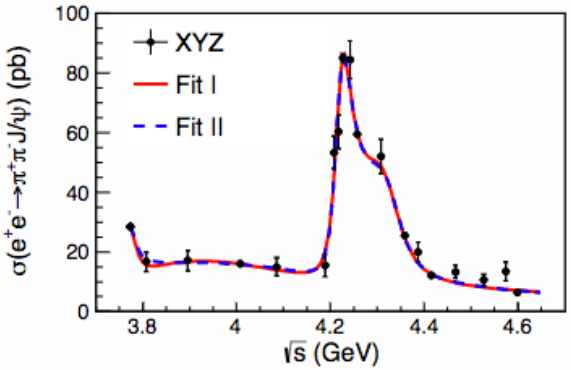


- **While not seen yet in B decays**

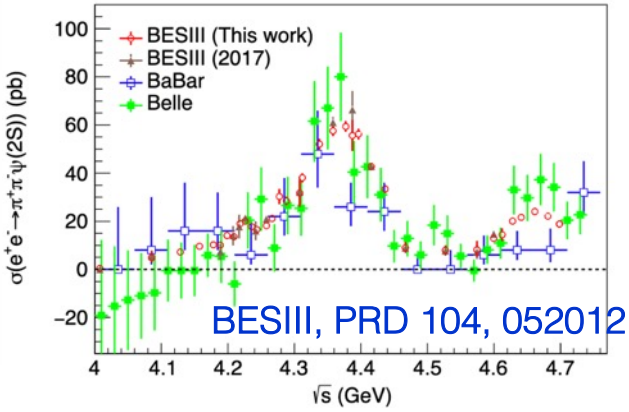
$B^{\pm,0} \to K^{\pm,0}\pi^+\pi^- J/\psi$



- **Improved knowledges from BESIII**



BESIII, PRL118, 092001 (2017)

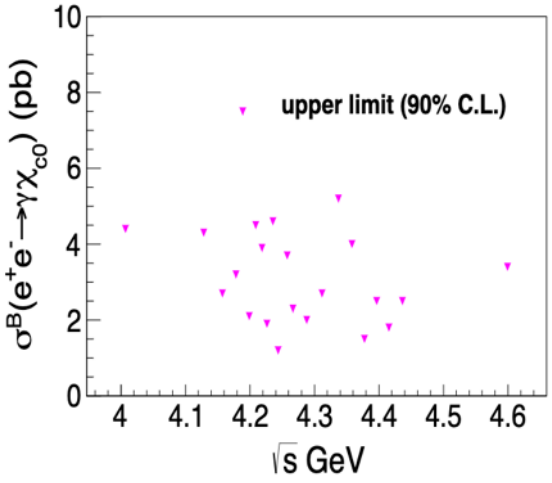


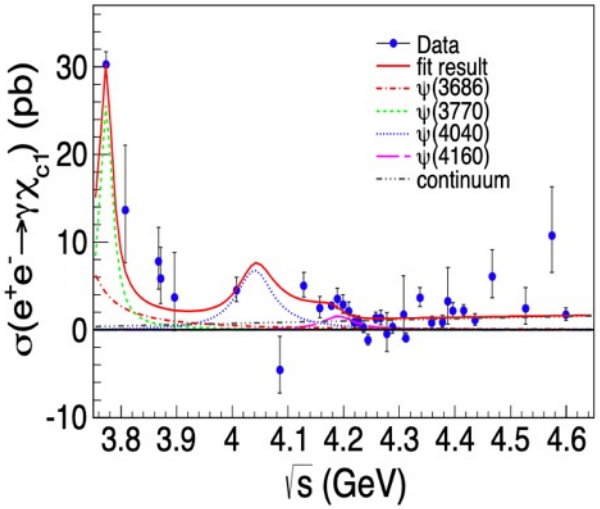
BESIII, PRD 104, 052012 (2021)

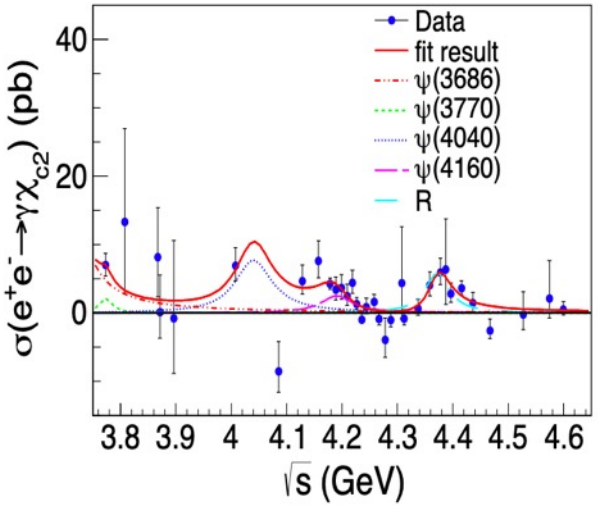
$e^+e^- \to \gamma\chi_{cJ}$ at $\sqrt{s}$=3.8-4.6 GeV

PRD 104, 092001 (2021)

- No signals for $e^+e^- \to \gamma\chi_{c0}$
- Observations of $e^+e^- \to \gamma\chi_{c1,2}$







- $\gamma\chi_{c1}$: Well describe with conventional charmonium states
- $\gamma\chi_{c2}$: Along with conventional ones, an additional Y state is needed

$$M = 4371.7 \pm 7.5 \pm 1.8\ \mathrm{MeV}/c^2\ ,\quad \Gamma = 51.1 \pm 17.6 \pm 1.9\ \mathrm{MeV}$$

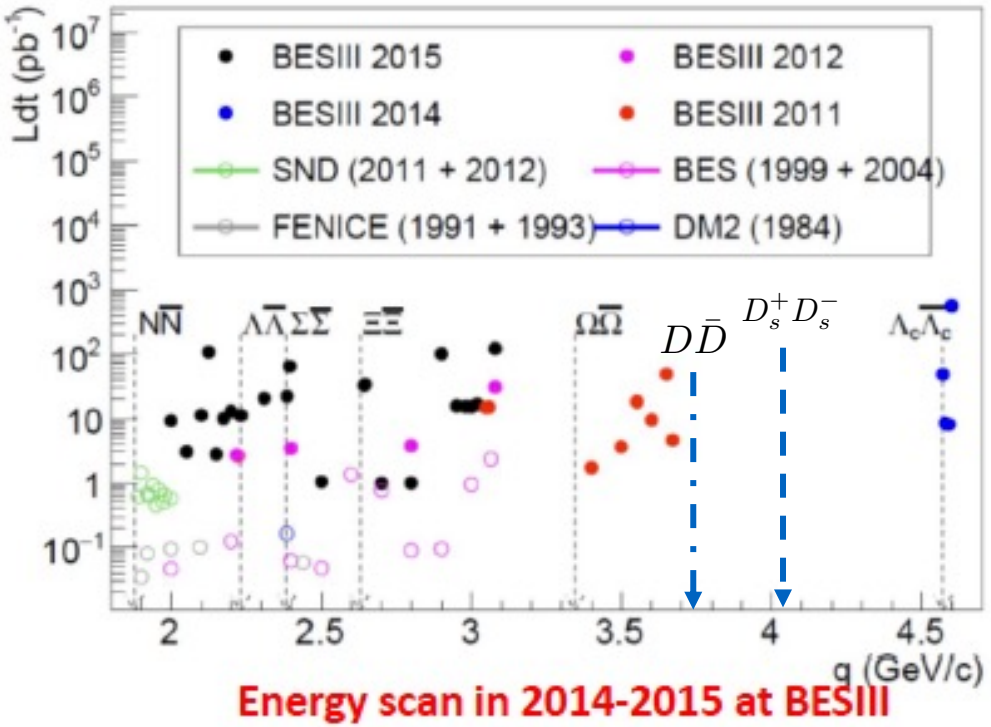
✓ statistical significance of 5.8 σ

✓ consistent with the Y(4360)/Y(4390)

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}, $D_s\bar{D}_s^*$
4.6-4.7 GeV, 4.4 fb^{-1}, $\Lambda_c\bar{\Lambda}_c$



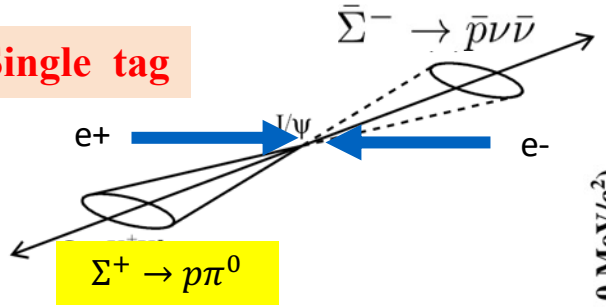
Energy scan in 2014-2015 at BESIII

- **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;**

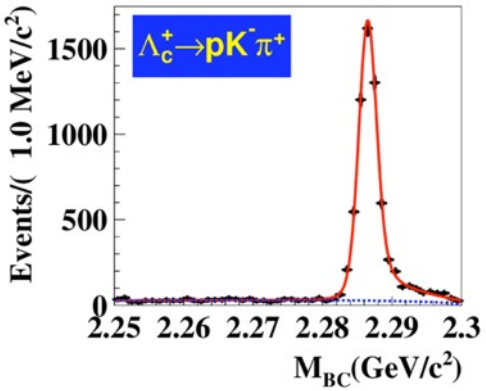
BESIII advantage: unique data near to the thresholds

- Known initial 4-momentum
- Known beam energy: pair productions
- Decay with neutron & π^0
- Decay with invisibles: neutrinos
- Missing mass or missing energy

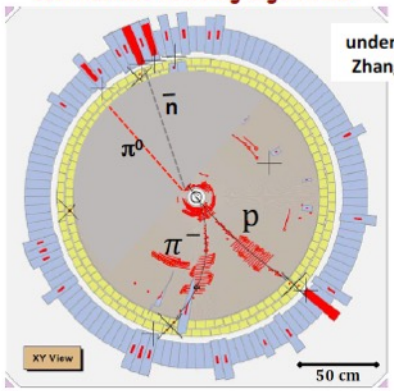
Single tag



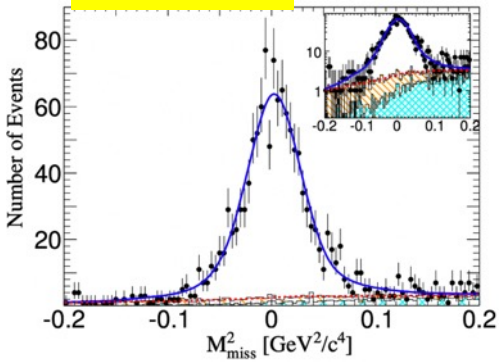
Excellent resolution
Beam-constraint Λ_c mass

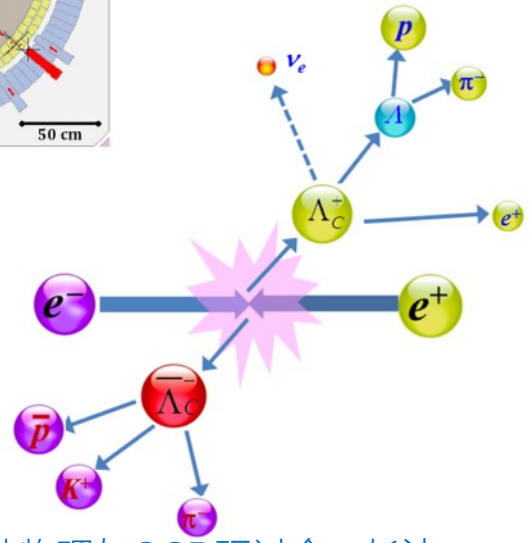


use machine-learning algorithms?



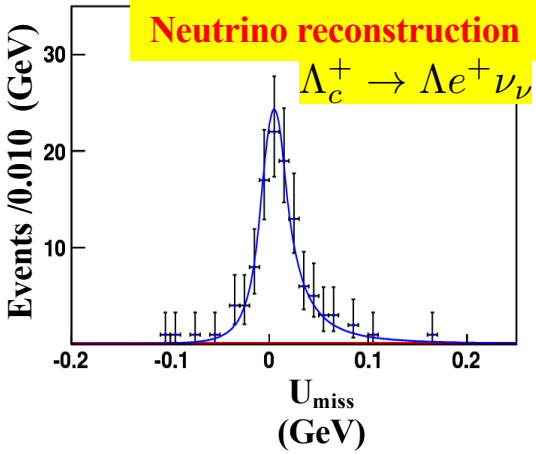
Missing mass





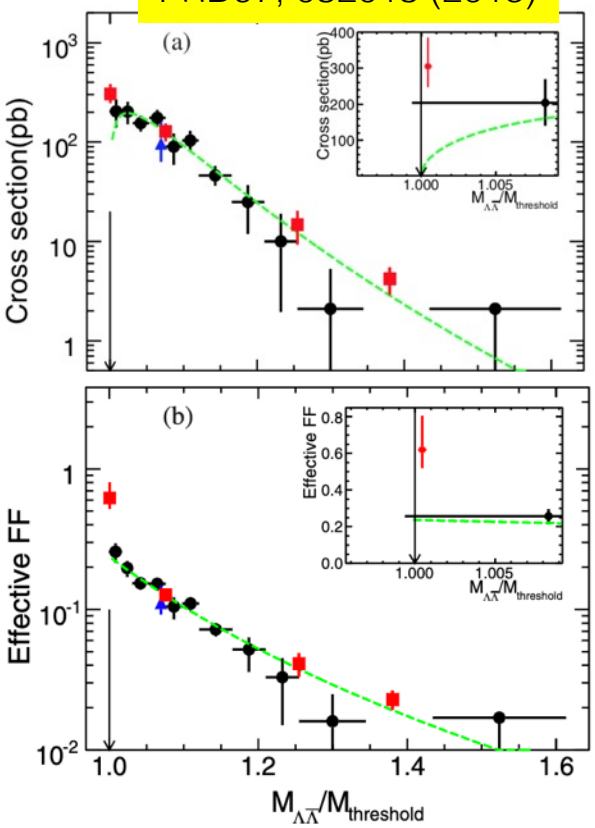
Neutrino reconstruction

$\Lambda_c^+ \to \Lambda e^+ \nu_\nu$

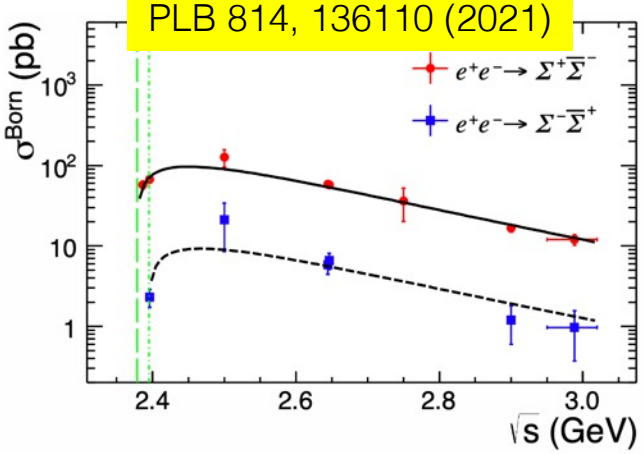


Hyperon production cross sections

PRD97, 032013 (2018)



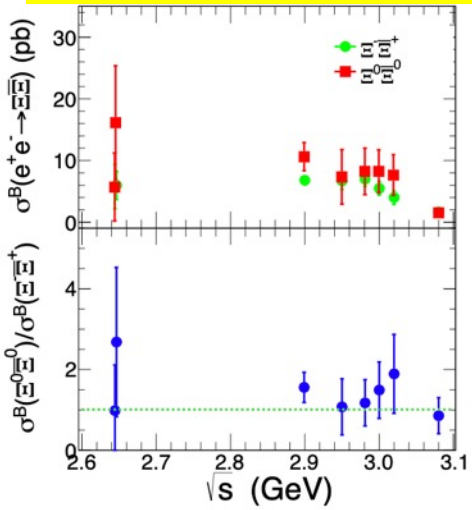
PLB 814, 136110 (2021)



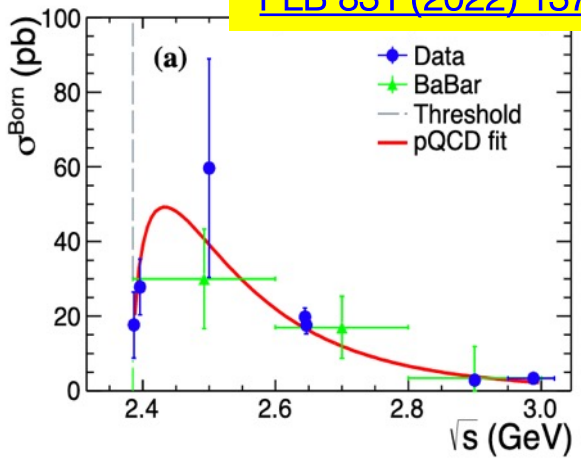
$$\frac{\sigma^{Born}(e^+e^- \to \Sigma^+\bar{\Sigma}^-)}{\sigma^{Born}(e^+e^- \to \Sigma^-\bar{\Sigma}^+)} = 9.7 \pm 1.3$$

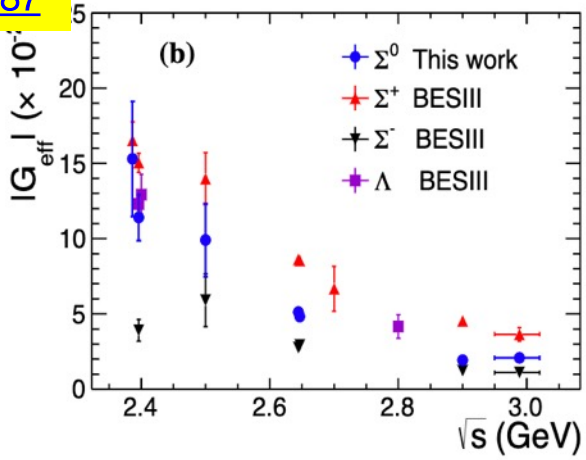
consistent with the prediction of Phys.Lett.B 799 (2019) 135041

PRD103, 012005 (2021)
PLB 820, 136557 (2021)



PLB 831 (2022) 137187

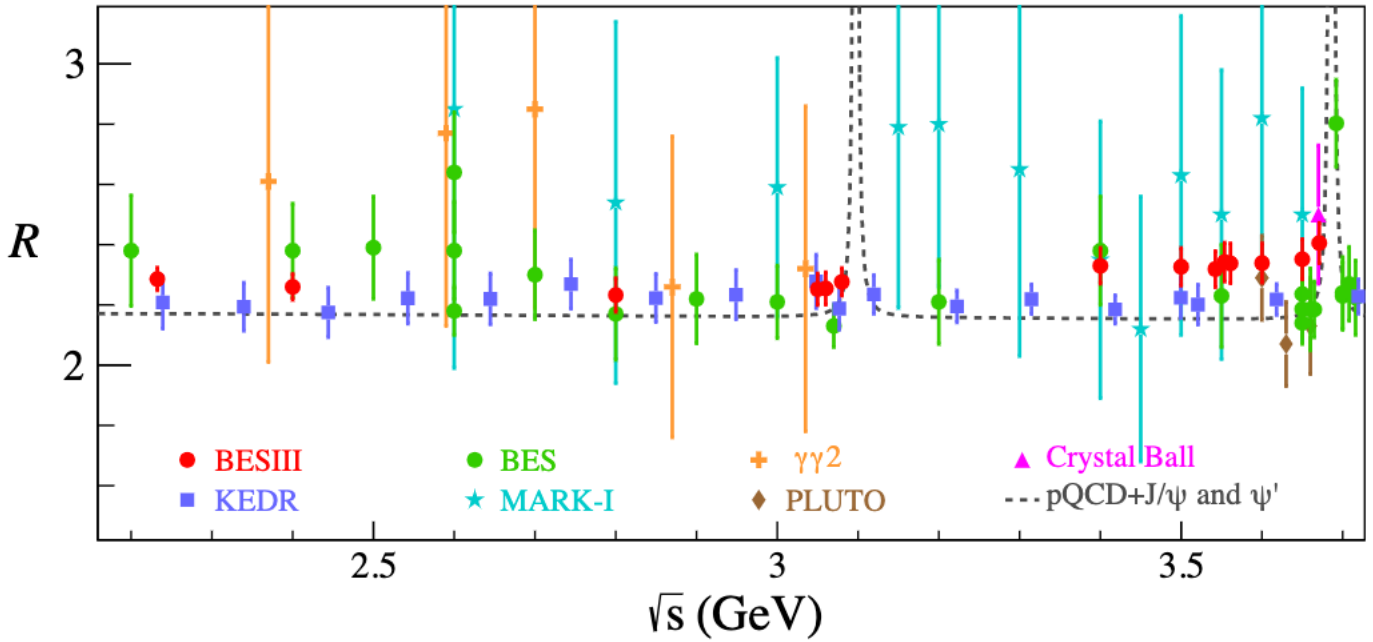




R values at BESIII

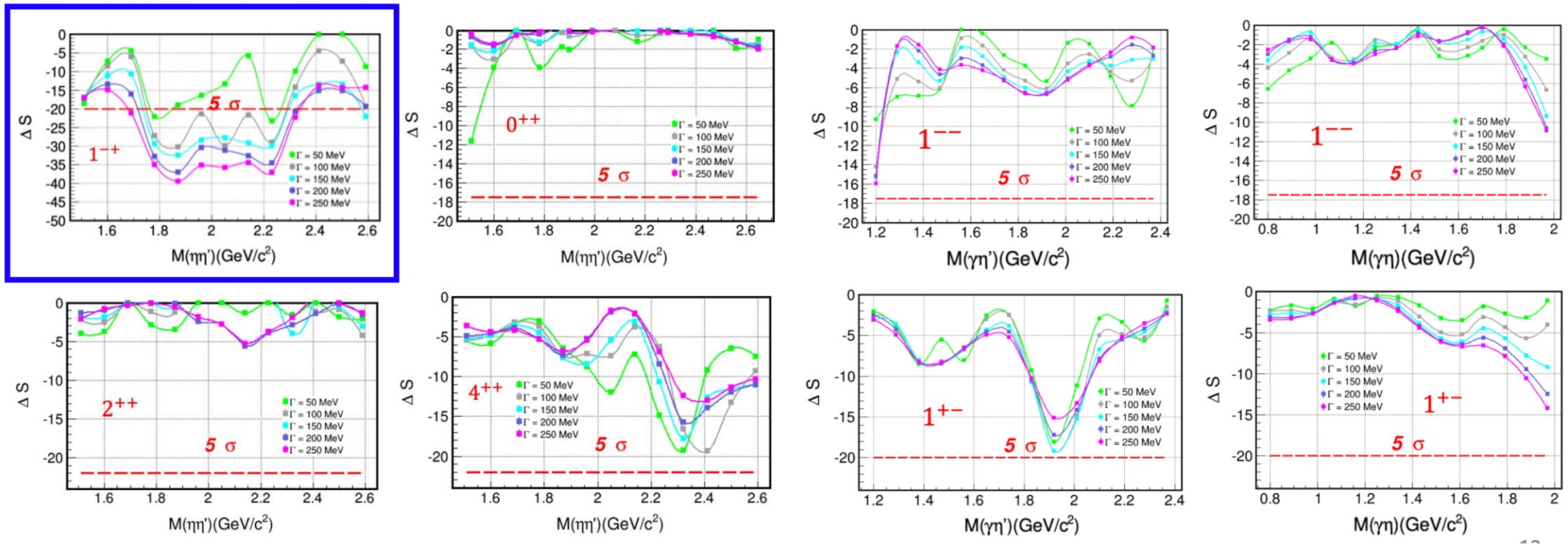
PRL128, 062004 (2022)

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.

scans of additional resonance with different J^{PC}, masses and widths



Further checks on the 1^{-+} state $\eta_1(1855)$

Angular distribution as a function of $M(\eta\eta')$ can be expressed model-independently in terms of Legendre polynomial moments

$$\langle Y_l^0 \rangle \equiv \sum_{i=1}^{N_k} W_i Y_l^0(\cos\theta_\eta^i)$$

- for data, W_i is to implement background subtraction
- for MC, W_i is intensity for each event calculated in the PWA

The moments are related to the spin-0 (S), spin-1 (P) and spin-2 (D) amplitudes by

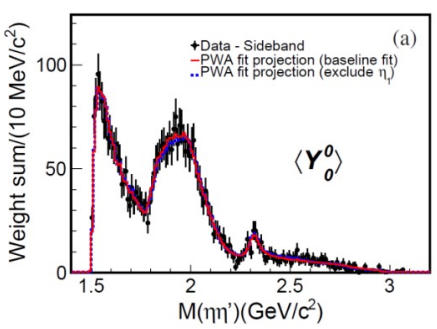
$$\sqrt{4\pi}\langle Y_0^0 \rangle = S^2 + P^2 + D^2$$

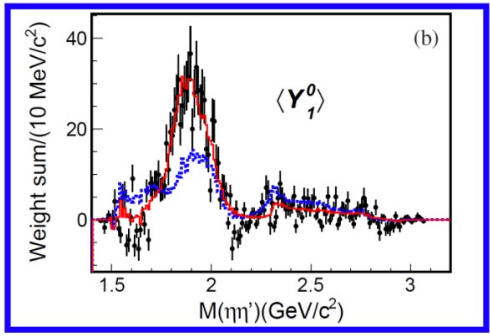
$$\sqrt{4\pi}\langle Y_1^0 \rangle = 2SP\cos\phi_P + 4PD\cos(\phi_P - \phi_D)$$

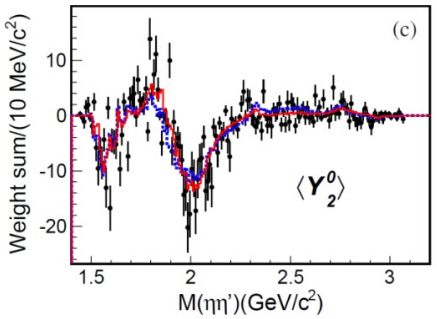
$$\sqrt{4\pi}\langle Y_2^0 \rangle = \frac{2}{\sqrt{5}}P^2 + \frac{2\sqrt{5}}{7}D^2 + 2SD\cos\phi_D$$

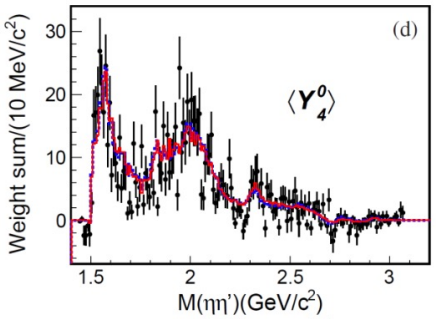
$$\sqrt{4\pi}\langle Y_4^0 \rangle = \frac{6}{7}D^2$$

need for the $\eta_1(1855)$ P-wave









21