Hadron Spectroscopy at the BESIII Experiment

Ryan Mitchell (Indiana University)

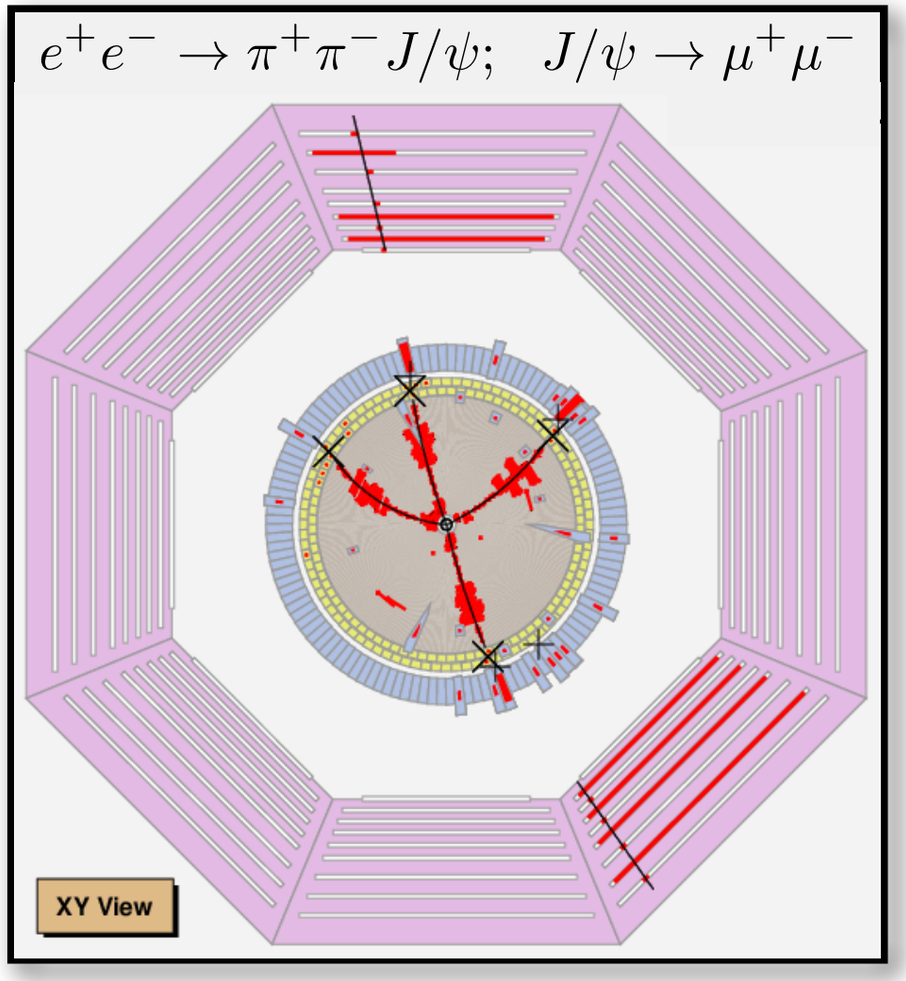
Snowmass Cincinnati Meeting, May 17, 2022

BEPCII: Beijing Electron Positron Collider

symmetric e^+e^-collisions at E_{CM} between 2.0 and 5.0 GeV

BESIII: Beijing Spectrometer

a versatile detector covering 93% of 4π



running since 2009 at the Institute of High Energy Physics in Beijing, China

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	10 billion J/ψ decays	*glueballs, hybrids, coupled-channel analyses*	no plans (analyze current data)
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$	2.7 billion $\psi(2S)$ decays	*further explorations in J/ψ, $\psi(2S)$, and other charmonium decays*	
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma$ + ccbar $\psi(2S) \to \pi h_c$ decays of η_c & h_c		*rare and precision transitions; properties of ψ_2; search for η_{c2}…*	
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$	> 20 fb^{-1} of data at E_{cm} above 4 GeV	*more data; coupled-channel analyses of e^+e^- cross sections*	BEPCII-U UPGRADE: (1) 3× luminosity for E_{cm} above 4 GeV (2) maximum energy increase from 5 to 5.6 GeV ⇒ much larger data sets above 4 GeV (plans are being made); and expanded energy reach into new territory
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ *(PWA)* $Zc(4020) \to \pi h_c$ $Zcs(3985) \to DsD^*$		*new Z_c and Z_{cs} decays; E_{cm} dependence; coupled-channels…*	
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872)$ $X(3872) \to \pi\chi_{c1}$ $X(3872) \to DD^*$		*increased precision and searches for new X(3872) decay modes*	
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(2317)$ $ee \to DsD(^*)K$	> 3 fb^{-1} above $\Lambda_c\Lambda_c$ threshold	*access to more D and D_s excited states*	
CHARMED BARYON SPECTROSCOPY	decays of the Λ_c		*access to the Σ_c, Ξ_c, Ω_c (and excitations), and possibly the P_c*	

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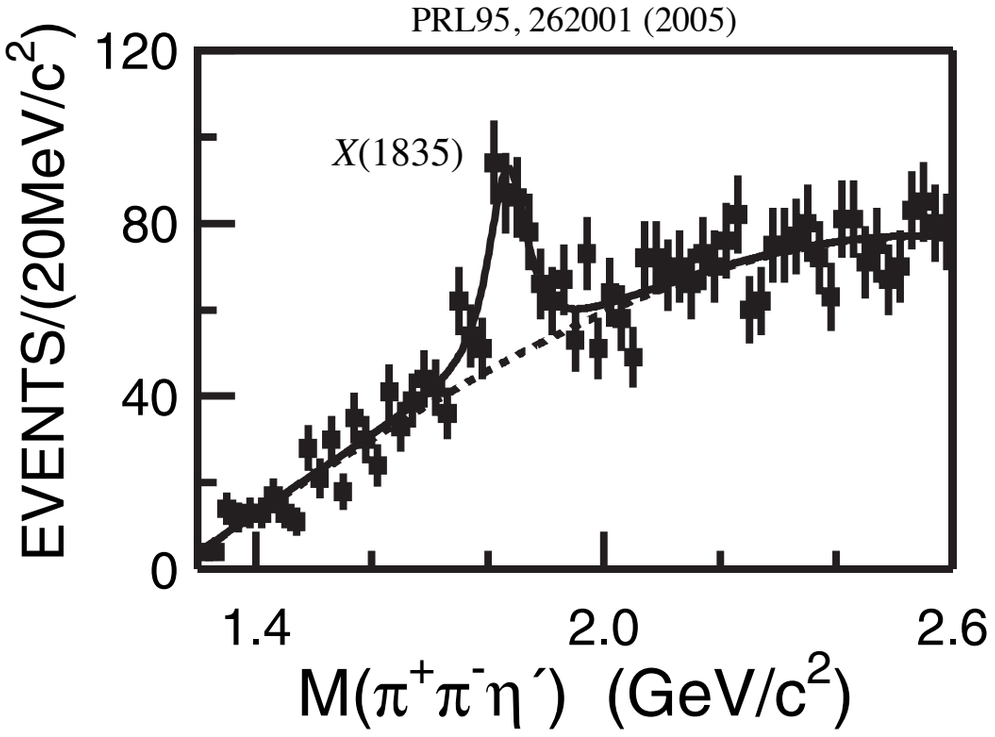
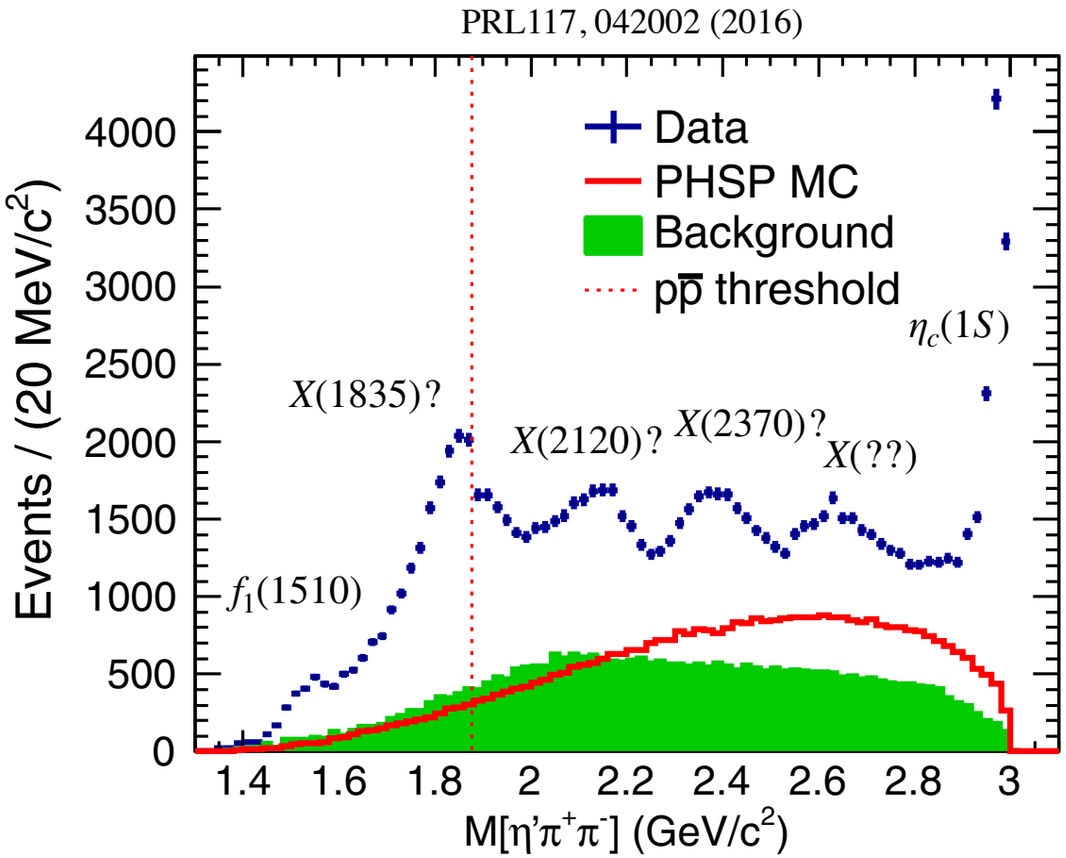
TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	10 billion J/ψ decays	*glueballs, hybrids, coupled-channel*	
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to p\bar{p}\pi$	2.7 bi… $\psi(2S)$		
CHARMONIUM SPECTROSCOPY	$ee \to DsD(*)K$	… fb^{-1} … thres…		
CHARMED BARYON SPECTROSCOPY	*decays of the* Λ_c		*(and excitations), and possibly the* P_c	reach into new territory

$J/\psi \to \gamma\pi^+\pi^-\eta'$ (58M J/ψ)



$J/\psi \to \gamma\pi^+\pi^-\eta'$ (1.1B J/ψ)



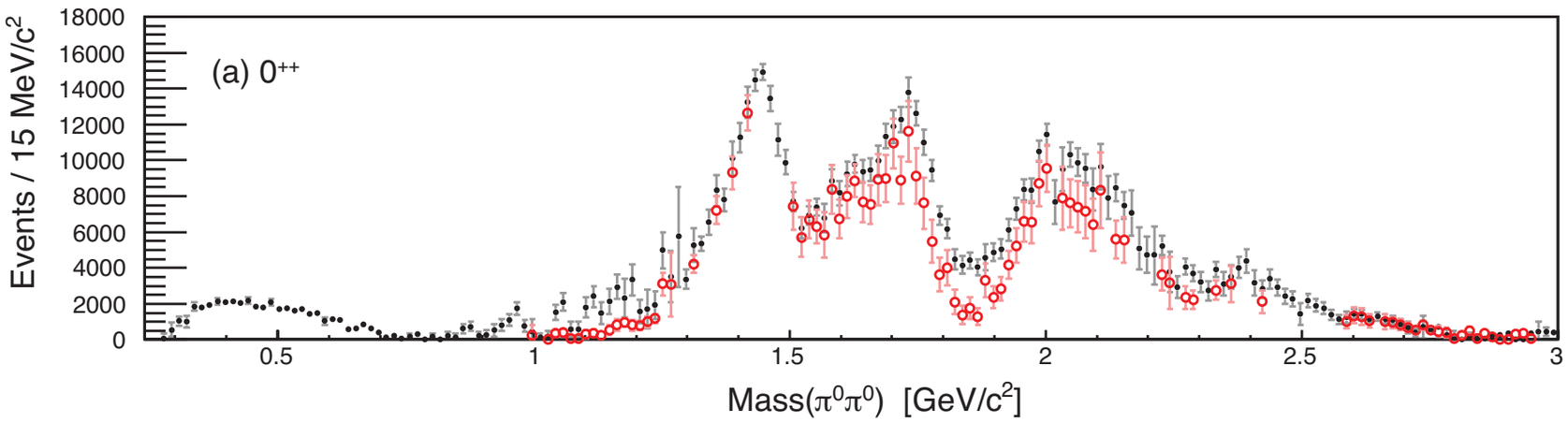
$\Longrightarrow$ *Improved statistics bring new challenges and opportunities.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	10 billion J/ψ decays	*glueballs, hybrids, coupled-channel analyses*	no plans (current data)
LIGHT BARYON SPECTROSC	$\psi(2S) \to p\bar{p}\pi$	2.7 billion	*further explorations*	
CHARMON SPECTROS				
"Y" MES SPECTROS				U UPGRADE:
"Z" MES SPECTROS				luminosity bove 4 GeV
"X" MES SPECTROS				mum energy ase from 5.6 GeV
CHARMED M SPECTROS				larger data ove 4 GeV being made);
CHARMED B SPECTROS				nded energy into new rritory

$J/\psi \to \gamma\pi^0\pi^0$ (1.3B J/ψ)

PRD92, 052003 (2015)



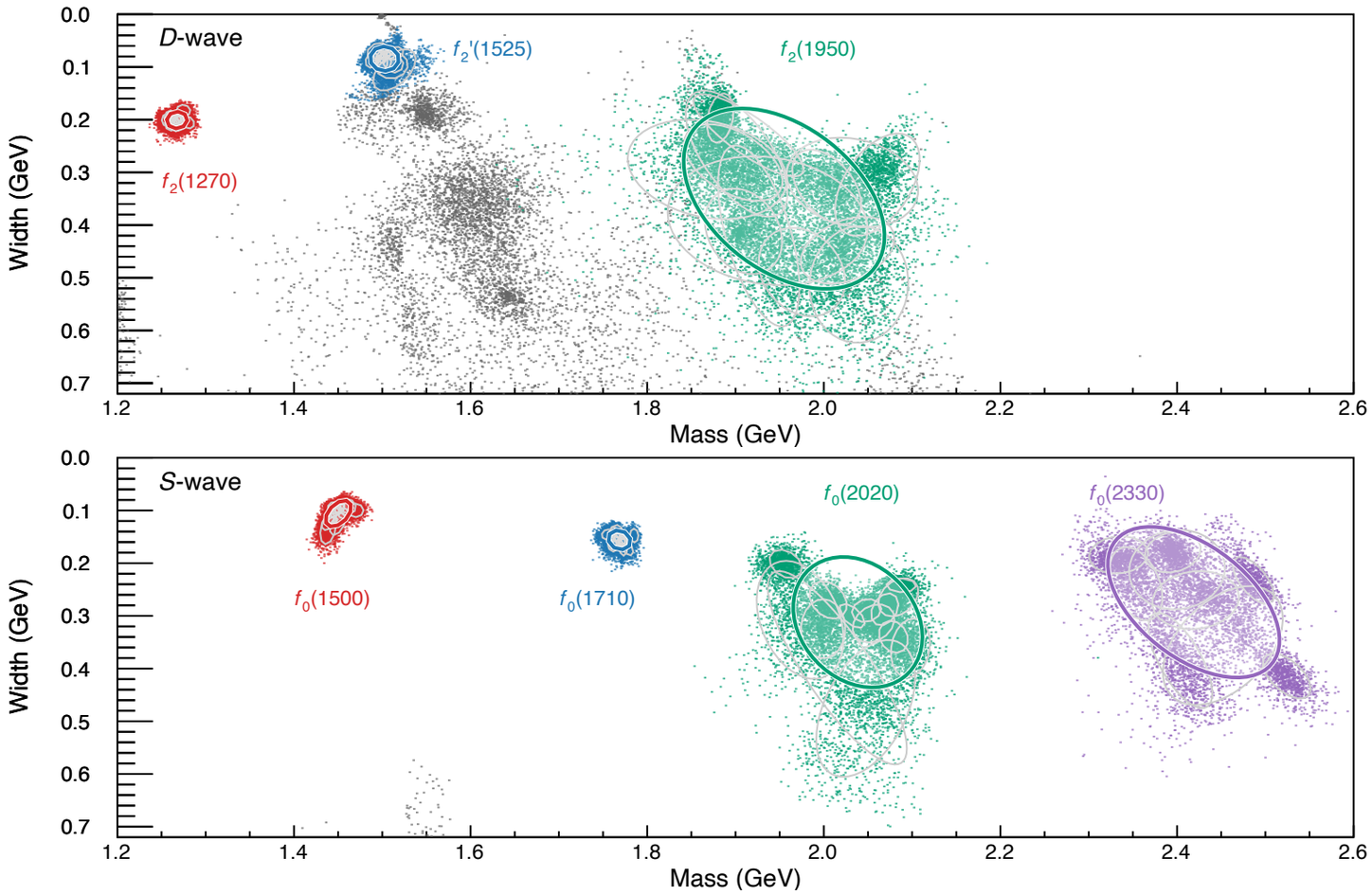
$\Longrightarrow$ *Radiative J/ψ decays are a key component in glueball searches.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	10 billion J/ψ decays	*glueballs, hybrids, coupled-channel analyses*	no plans ze current data)
LIGHT BARYON SPECTROSCOPY				
CHARMONIUM SPECTROSCOPY				
"Y" MESON SPECTROSCOPY				-U UPGRADE:
"Z" MESON SPECTROSCOPY				× luminosity n above 4 GeV
"X" MESON SPECTROSCOPY				ximum energy rease from o 5.6 GeV
CHARMED MESON SPECTROSCOPY				ch larger data above 4 GeV re being made);
CHARMED BARYON SPECTROSCOPY				panded energy ch into new territory

JPAC, Coupled-channel Analysis of $J/\psi \to \gamma\pi\pi$ and γKK

EPJC82, 80 (2022)



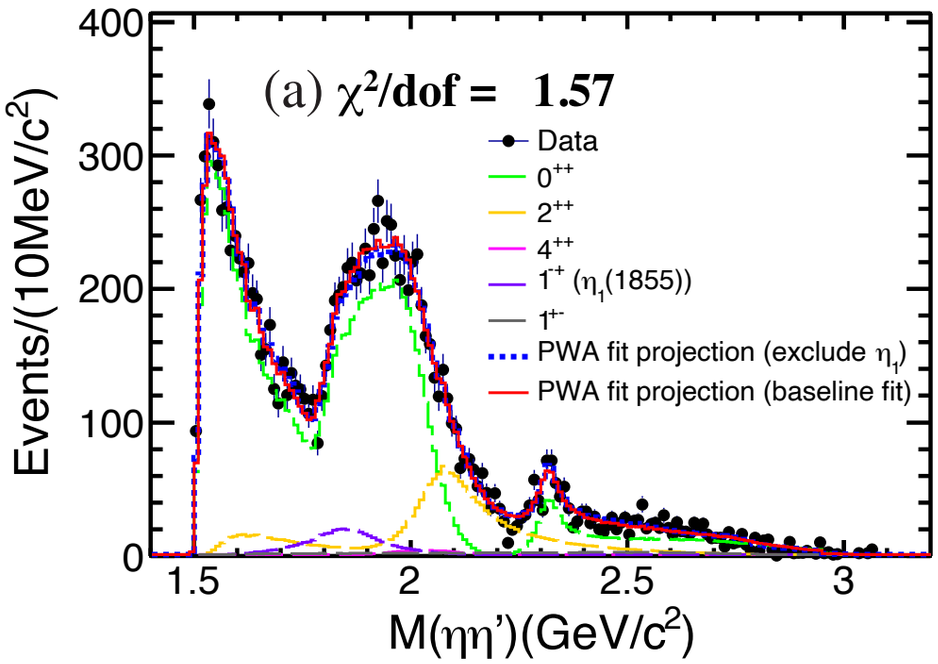
$\Longrightarrow$ *Multiple channels must be analyzed simultaneously to probe coupled-channel effects.*

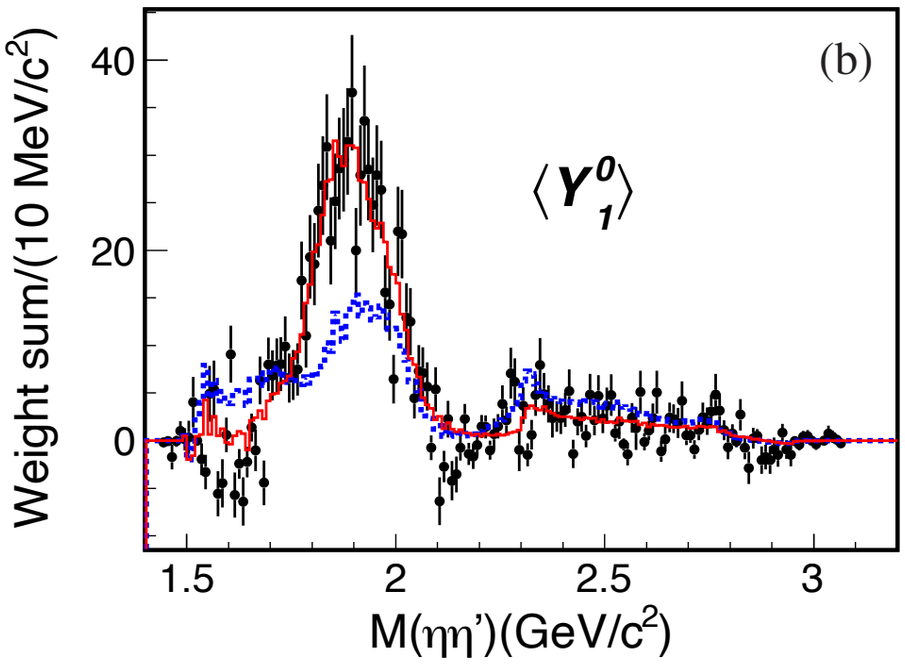
Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	10 billion J/ψ decays	*glueballs, hybrids, coupled-channel analyses*	
LIGHT BARYON SPECTROSCOPY			*further explorations*	
CHARMONIUM SPECTROSCOPY				
"Y" MESON SPECTROSCOPY				
"Z" MESON SPECTROSCOPY				
"X" MESON SPECTROSCOPY				
CHARMED MESON SPECTROSCOPY				
CHARMED BARYON SPECTROSCOPY			*and possibly the P_c*	territory

Discovery of the $\eta_1(1855)$ in $J/\psi \to \gamma\eta\eta'$ (10B J/ψ)

arXiv: 2202.00621





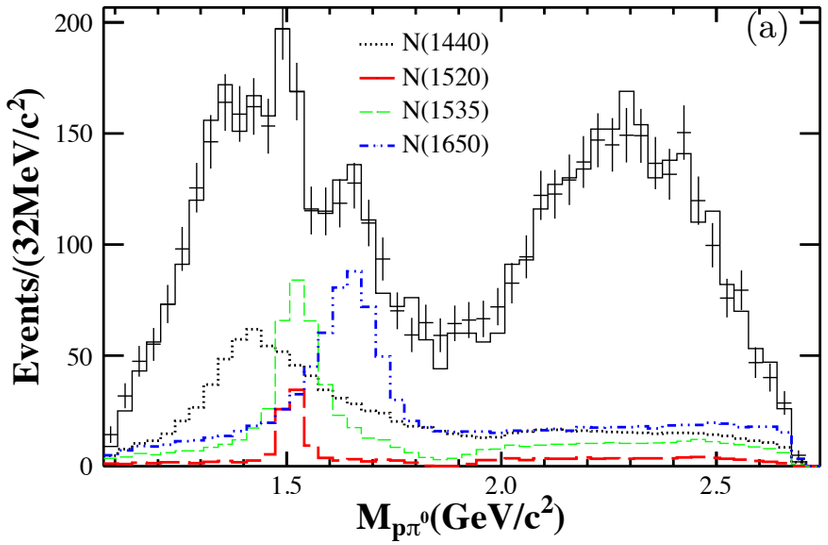
$\Longrightarrow$ *Hybrid mesons (or at least exotic J^{PC} mesons) are also produced in J/ψ radiative decays.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURR DAT
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	1(J/
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$	2. ψ(2
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma$ + ccbar $\psi(2S) \to \pi\, h_c$ decays of η_c & h_c	
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$	
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ (PWA) $Zc(4020) \to \pi h_c$ $Zcs(3985) \to DsD^*$	> 20 at E_{cm}
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872)$ $X(3872) \to \pi\chi_{c1}$ $X(3872) \to DD^*$	
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(2317)$ $ee \to DsD(^*)K$	> 3 fb^{-} th
CHARMED BARYON SPECTROSCOPY	decays of the Λ_c	

$\psi(2S) \to p\bar{p}\pi^0$ (106M $\psi(2S)$)

PRL110, 022001 (2013)



$\Longrightarrow$ *Baryon spectroscopy can be advanced using $\psi(2S)$ and other charmonium decays.*

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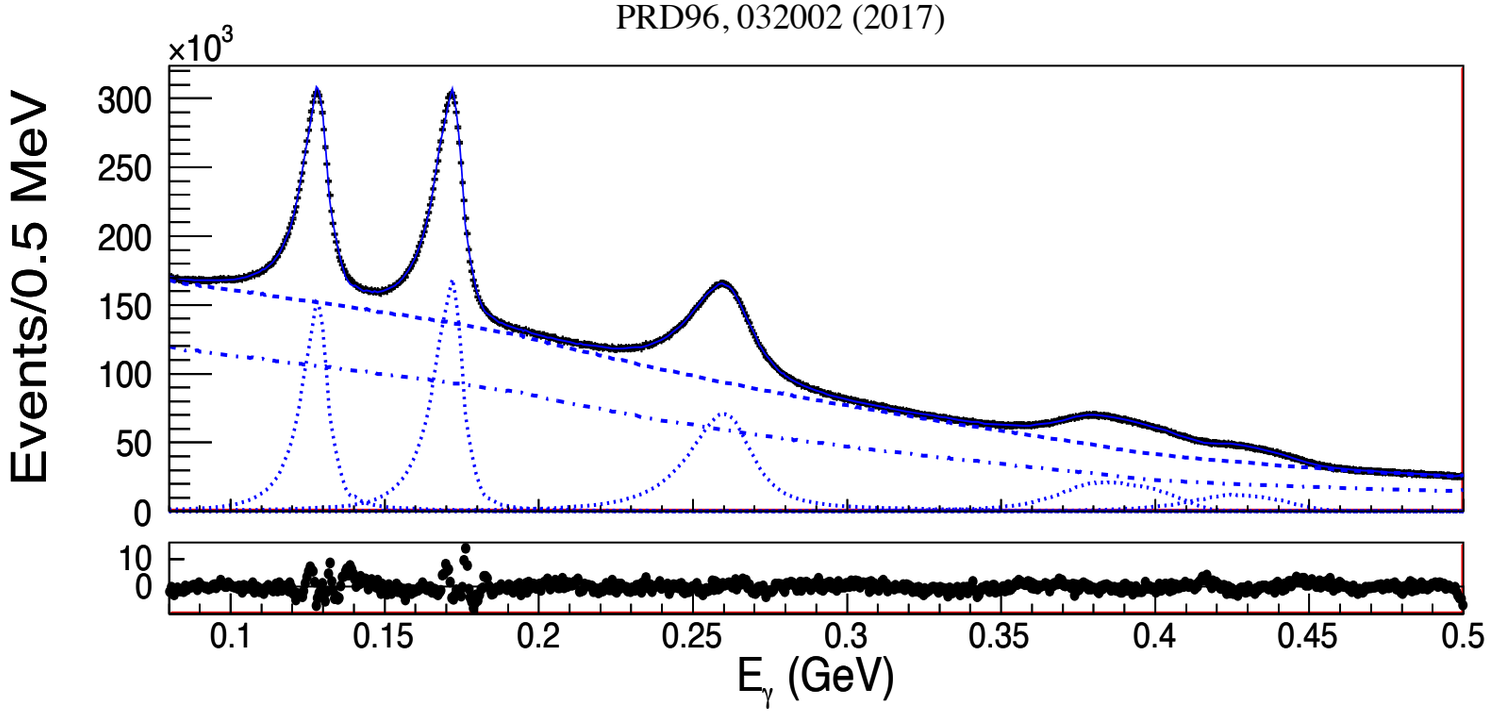
TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma$ $J/\psi \to$	10 billion	*glueballs, hybrids,*	data)
LIGHT BARYON SPECTROSCOPY	$\psi(2S)$ $\psi(2S)$ $\psi(2S)$			
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to$ $\psi(2S)$ *decays*			
"Y" MESON SPECTROSCOPY	$ee \to$ $ee \to$ $ee \to$			ADE:
"Z" MESON SPECTROSCOPY	$Zc(3900) \to$ $Zc(402$ $Zcs(3985$			ity GeV
"X" MESON SPECTROSCOPY	$ee \to \gamma$ $X(3872$ $X(3872)$			ergy n V
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(2317)$ $ee \to DsD(^*)K$	> 3 fb^{-1} above $\Lambda_c\Lambda_c$ threshold	*access to more D and D_s excited states*	larger data sets above 4 GeV (plans are being made); and expanded energy reach into new territory
CHARMED BARYON SPECTROSCOPY	*decays of the Λ_c*		*access to the Σ_c, Ξ_c, Ω_c (and excitations), and possibly the P_c*	

$\psi(2S) \to \gamma$ + hadrons (106M $\psi(2S)$)

PRD96, 032002 (2017)



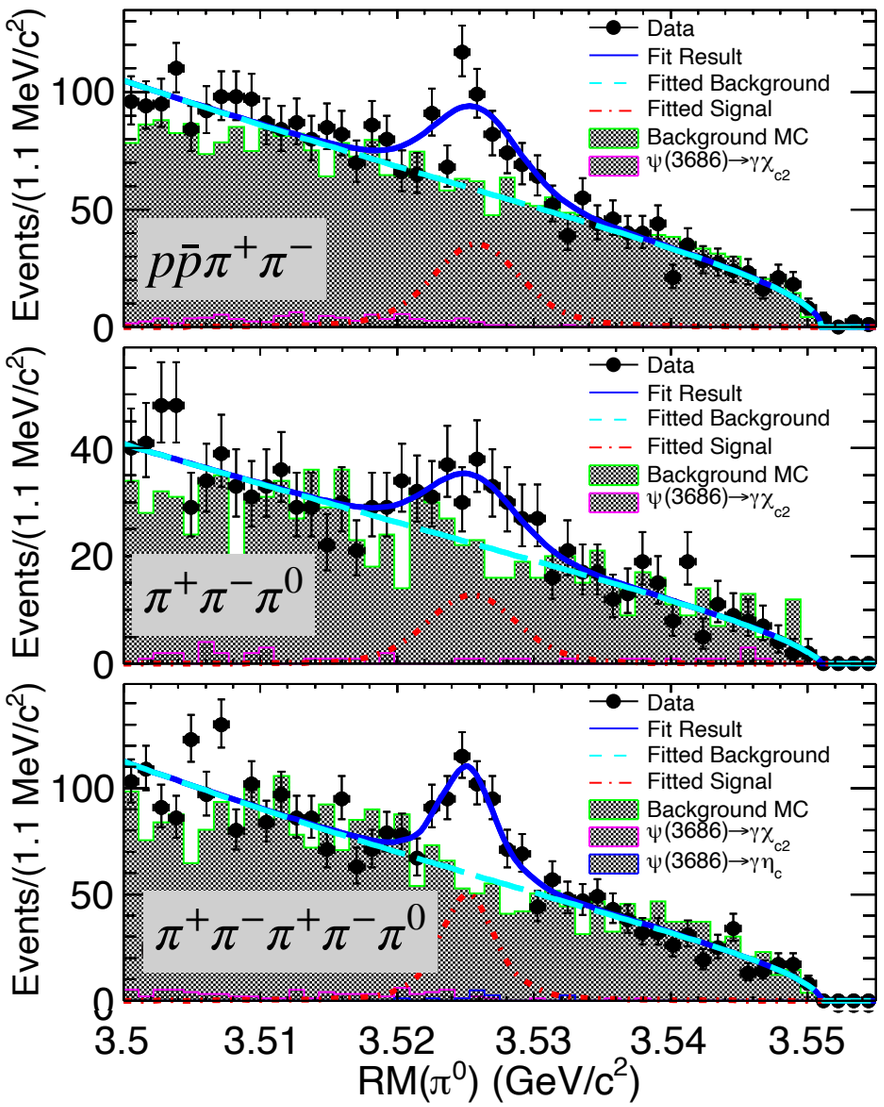
$\Longrightarrow$ *The $\psi(2S)$ data provides access to other charmonium states and provides opportunities for precision measurements.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma + ccbar$ $\psi(2S) \to \pi\, h_c$ *decays of* η_c *&* h_c
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ (P $Zc(4020) \to \pi h_c$ $Zcs(3985) \to DsD$
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872)$ $X(3872) \to \pi\chi_{c1}$ $X(3872) \to DD^*$
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(231$ $ee \to DsD(^*)K$
CHARMED BARYON SPECTROSCOPY	*decays of the* Λ_c

$\psi(2S) \to \pi^0 h_c$ with h_c to hadrons (448M $\psi(2S)$)

PRD99, 072008 (2019)



$\Longrightarrow$ *Traditionally difficult states, like the* $h_c(1P)$*, can be studied in detail using both the* $\psi(2S)$ *data and higher-energy data.*

Hadron Spectroscopy at the BESIII Experiment

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LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$	2.7 billion $\psi(2S)$ decays	*further explorations in J/ψ, $\psi(2S)$, and other charmonium decays*	
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma$ + ccbar $\psi(2S) \to \pi h_c$ decays of η_c & h_c		*rare and precision transitions; properties of ψ_2; search for η_{c2}…*	
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$	> 20 fb^{-1} of data at E_{cm} above 4 GeV	*more data; coupled-channel analyses of e^+e^- cross sections*	BEPCII-U UPGRADE: (1) 3× luminosity for E_{cm} above 4 GeV (2) maximum energy increase from 5 to 5.6 GeV ⇒ much larger data sets above 4 GeV (plans are being made); and expanded energy reach into new territory
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ *(PWA)* $Zc(4020) \to \pi h_c$ $Zcs(3985) \to DsD^*$		*new Z_c and Z_{cs} decays; E_{cm} dependence; coupled-channels…*	
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872)$ $X(3872) \to \pi\chi_{c1}$ $X(3872) \to DD^*$		*increased precision and searches for new X(3872) decay modes*	
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(2317)$ $ee \to DsD(^*)K$	> 3 fb^{-1} above $\Lambda_c\Lambda_c$ threshold	*access to more D and D_s excited states*	
CHARMED BARYON SPECTROSCOPY	*decays of the Λ_c*		*access to the Σ_c, Ξ_c, Ω_c (and excitations), and possibly the P_c*	

Hadron Spectroscopy at the BESIII Experiment

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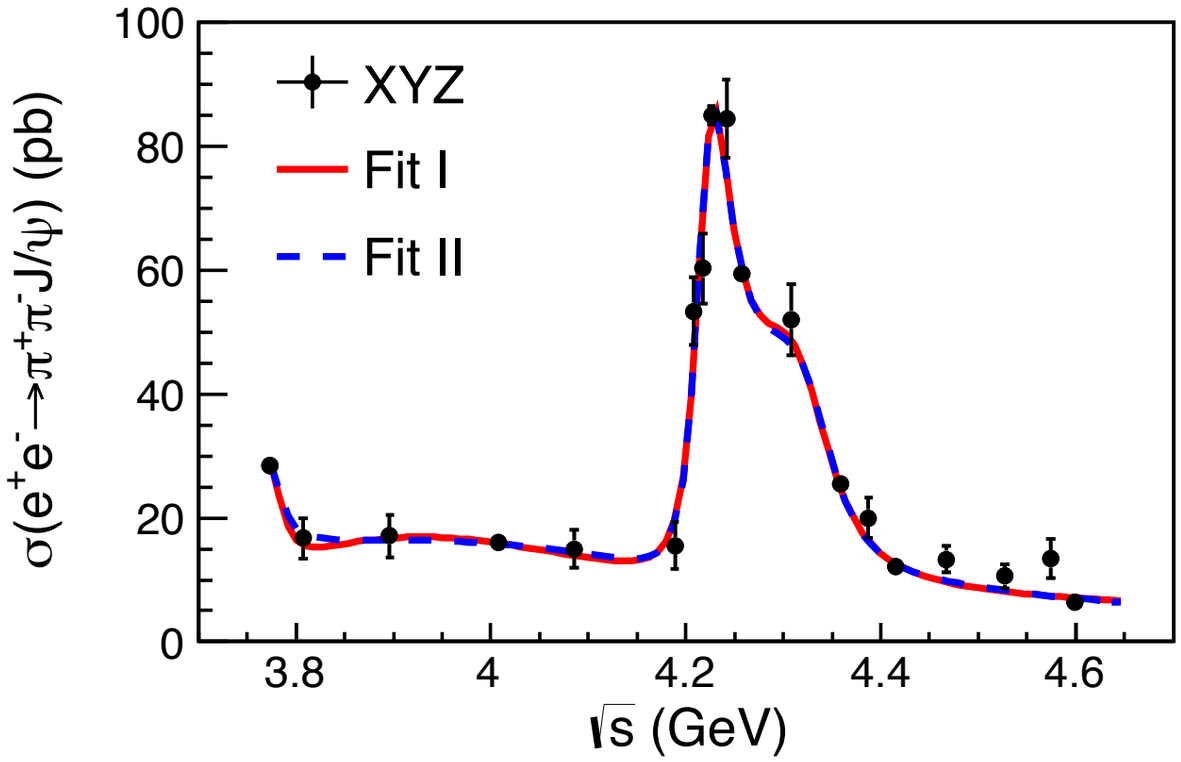
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta$	10 billion	*glueballs, hybrids,*	
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to$ $\psi(2S) \to$ $\psi(2S) \to$			ns ent data)
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma$ $\psi(2S) \to$ *decays of* η			
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi$ $ee \to \pi\pi\psi$ $ee \to D^*$			GRADE:
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi$ $Zc(4020)$ $Zcs(3985)$			nosity e 4 GeV
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3$ $X(3872) \to$ $X(3872) \to$			n energy from GeV
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds$ $ee \to DsD($			ger data 4 GeV being made);
CHARMED BARYON SPECTROSCOPY	*decays of the* Λ_c		*access to the* Σ_c, Ξ_c, Ω_c *(and excitations), and possibly the* P_c	and expanded energy reach into new territory

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

PRL118, 092001 (2017)



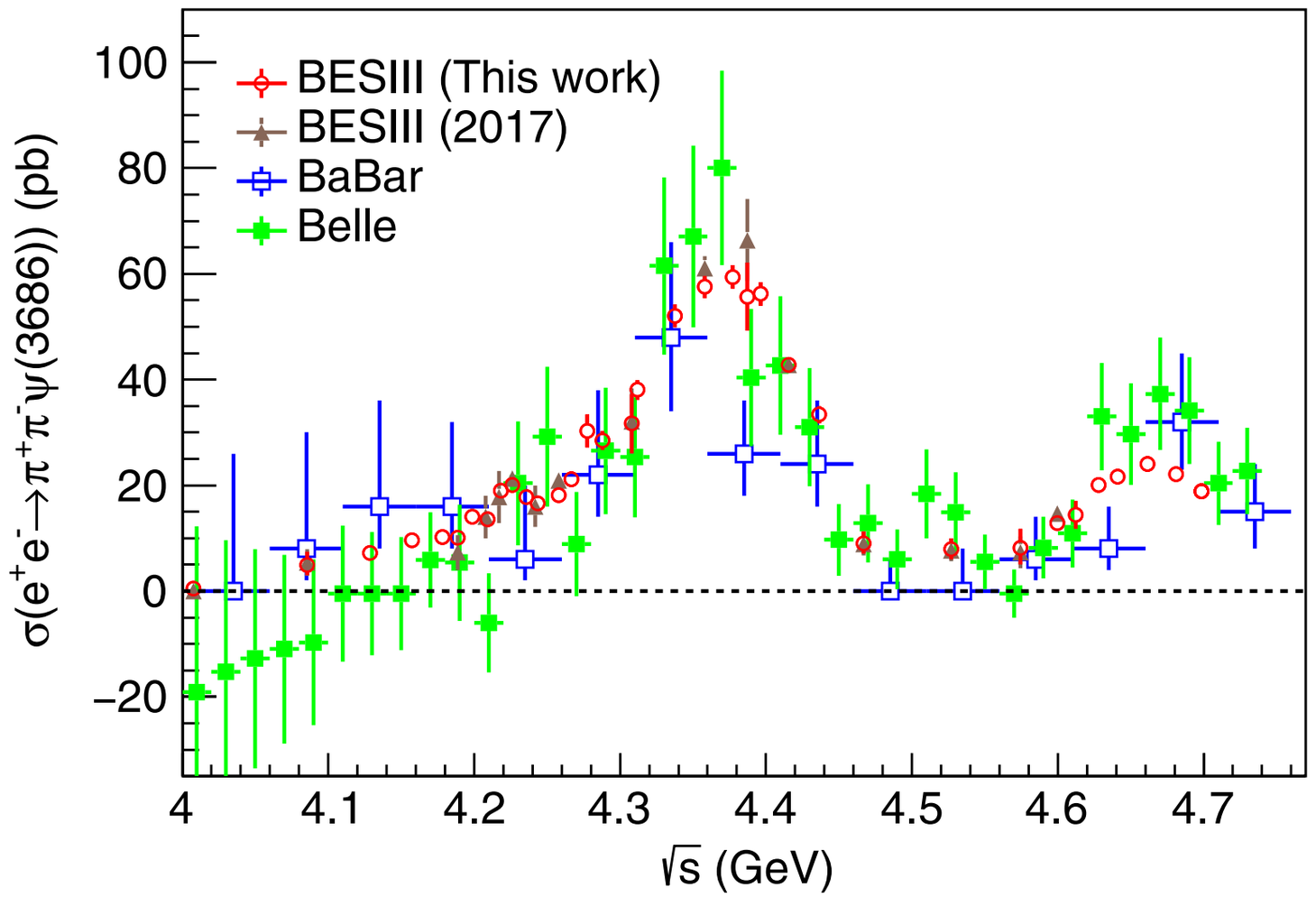
$\Longrightarrow$ *Exclusive cross sections are highly non-trivial.*
The original $Y(4260)$ *is not a simple peak.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	*J/ψ →* …			
LIGHT BARYON SPECTROSCOPY	*ψ(2S)* …			…data)
CHARMONIUM SPECTROSCOPY	*ψ(2S) →* …			
"Y" MESON SPECTROSCOPY	*ee →* …			…ADE:
"Z" MESON SPECTROSCOPY	*Zc(3900) →* …			…ity …GeV
"X" MESON SPECTROSCOPY	*ee → γ…* …			…ergy
CHARMED MESON SPECTROSCOPY	*ee → Ds** …			…data …eV …nade);
CHARMED BARYON SPECTROSCOPY	*decays of the Λ_c*		*(and excitations), and possibly the P_c*	…energy reach into new territory

$$e^+e^- \to \pi^+\pi^-\psi(2S)$$

PRD104, 052012 (2021)



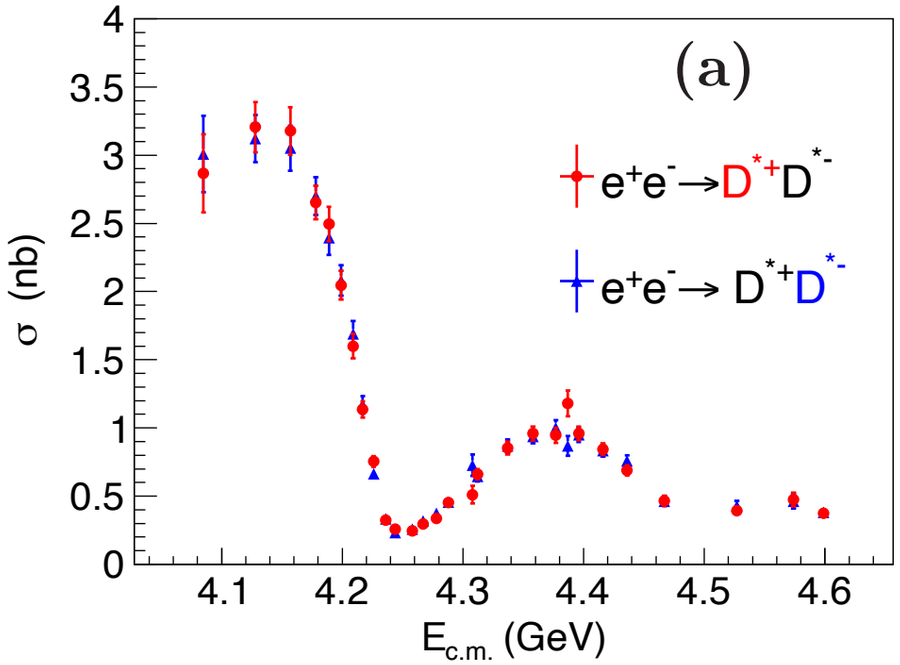
$\Longrightarrow$ *Other exclusive channels with charmonium also show non-trivial structure.*

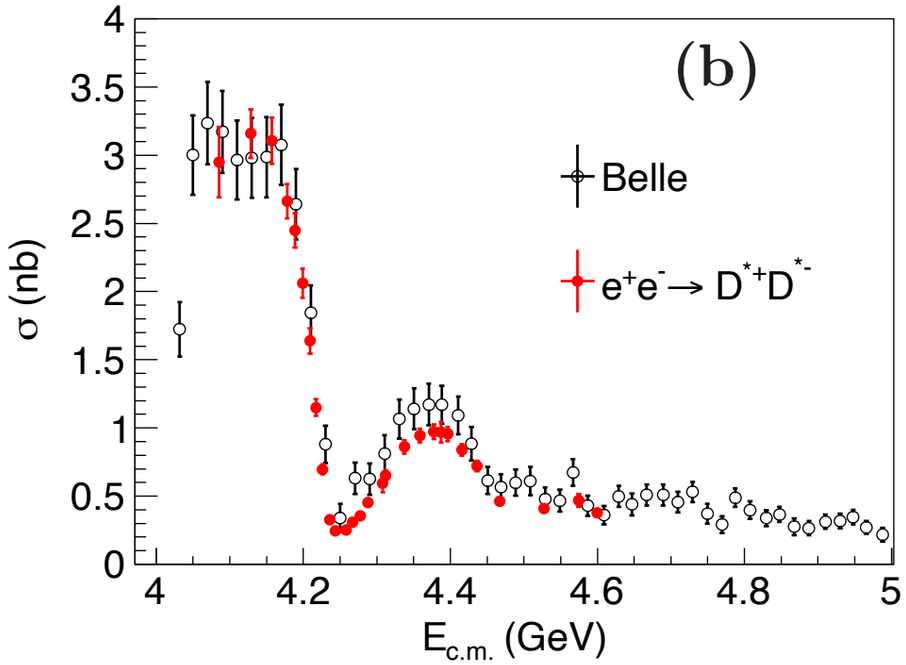
Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$	10 billion J/ψ decays	*glueballs, hybrids, coupled-channel*	
LIGHT BARYON SPECTROSCOPY				
CHARMONIUM SPECTROSCOPY				
"Y" MESON SPECTROSCOPY				
"Z" MESON SPECTROSCOPY				
"X" MESON SPECTROSCOPY				
CHARMED MESON SPECTROSCOPY				
CHARMED BARYON SPECTROSCOPY	*decays of the* Λ_c		*access to the* Σ_c, Ξ_c, Ω_c *(and excitations), and possibly the* P_c	and expanded energy reach into new territory

$$e^+e^- \to D^{*+}D^{*-}$$

arXiv:2112.06477





⟹ *The open-charm channels are larger and play a crucial role in the global picture of vector charmonium.*

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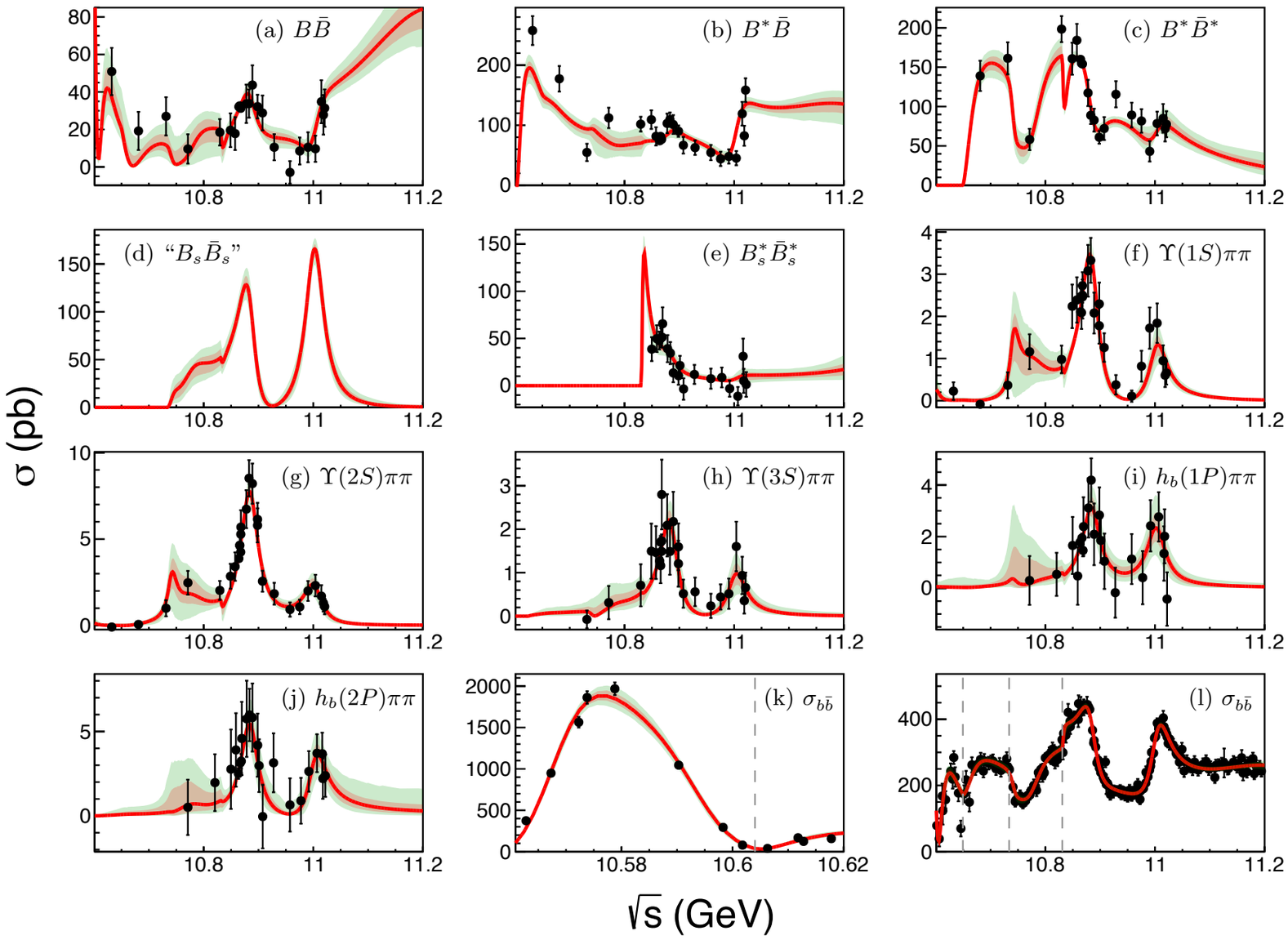
TOPIC	EX… ACH…
LIGHT MESON SPECTROSCOPY	
LIGHT BARYON SPECTROSCOPY	
CHARMONIUM SPECTROSCOPY	$\psi($ … d …
"Y" MESON SPECTROSCOPY	
"Z" MESON SPECTROSCOPY	$Zc(3$ … Z … Zc …
"X" MESON SPECTROSCOPY	… X … X …
CHARMED MESON SPECTROSCOPY	ee …
CHARMED BARYON SPECTROSCOPY	dec …

K-matrix Analysis of e^+e^- Annihilation in the Bottomonium Region

N. Hüsken,[1,2] R.E. Mitchell,[1] and E.S. Swanson[3]

arXiv:2204.11915



$\Longrightarrow$ *The infrastructure required to analyze many-channel systems is being developed.*

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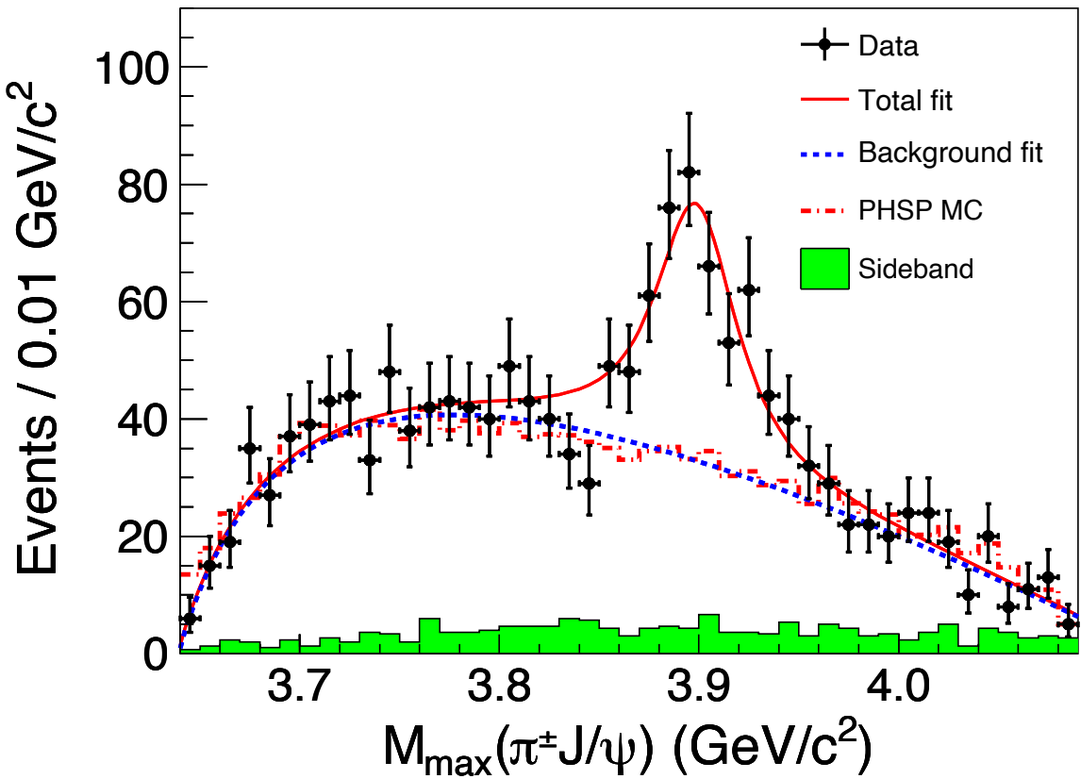
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$			
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma$ + ccbar $\psi(2S) \to \pi\, h_c$ decays of η_c & h_c			
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$			
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ *(PWA)* $Zc(4020) \to \pi h_c$ $Zcs(3985) \to DsD^*$	> at E		
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872)$ $X(3872) \to \pi\chi_{c1}$ $X(3872) \to DD^*$			
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(2317)$ $ee \to DsD(^*)K$	> 3 fb threshold	D_s excited states	sets above 4 GeV (plans are being made); and expanded energy reach into new territory
CHARMED BARYON SPECTROSCOPY	decays of the Λ_c		access to the Σ_c, Ξ_c, Ω_c (and excitations), and possibly the P_c	

$$e^+e^- \to Z_c(3900)\pi \to \pi^+\pi^- J/\psi$$

PRL110, 252001 (2013)



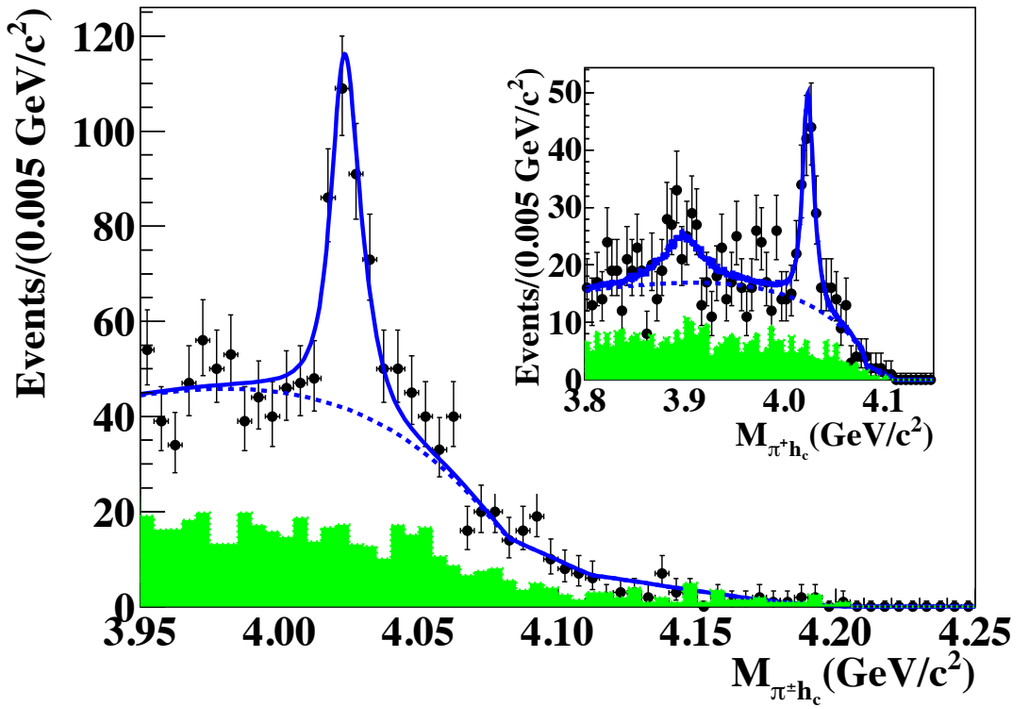
$\Longrightarrow$ *The isospin-1 $Z_c(3900)$ appears near DD* threshold.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	10 billion J/ψ decays	*glueballs, hybrids, coupled-channel*	
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$			lans rrent data)
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma$ + ccbar $\psi(2S) \to \pi\, h_c$ decays of η_c & h_c			
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$			UPGRADE:
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ *(PWA)* $Zc(4020) \to \pi h_c$ $Zcs(3985) \to DsD^*$	> at B		minosity ve 4 GeV
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872)$ $X(3872) \to \pi\chi_{c1}$ $X(3872) \to DD^*$			um energy e from 5 GeV
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(2317)$ $ee \to DsD(^*)K$	> 3 t		arger data ve 4 GeV re being made);
CHARMED BARYON SPECTROSCOPY	decays of the Λ_c		*access to the Σ_c, Ξ_c, Ω_c (and excitations), and possibly the P_c*	and expanded energy reach into new territory

$$e^+e^- \to Z_c(4020)\pi \to \pi^+\pi^- h_c$$

PRL111, 242001 (2013)



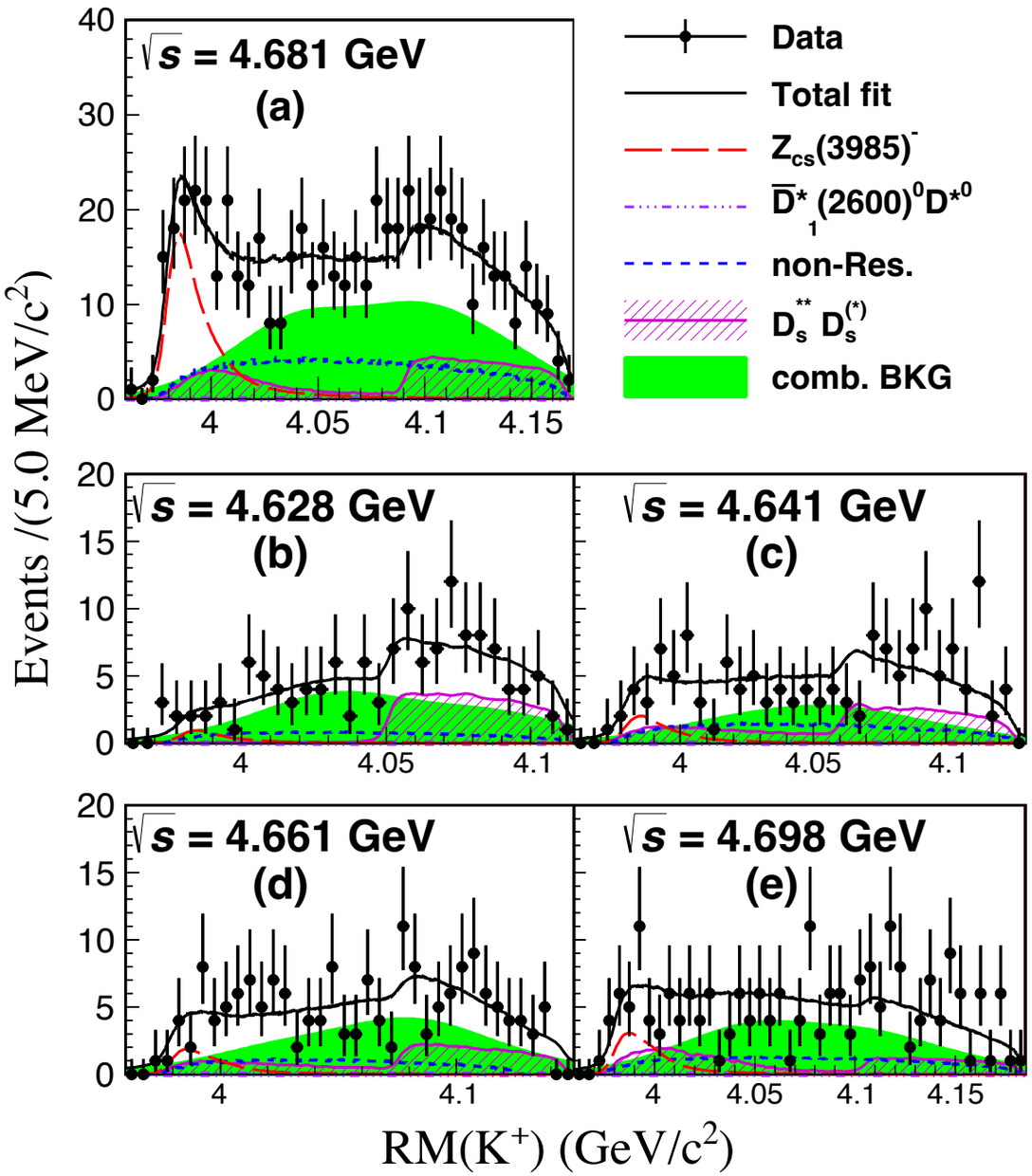
$\Longrightarrow$ *The isospin-1 $Z_c(4020)$ appears near D*D* threshold.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CU… D…
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$	
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma$ + ccbar $\psi(2S) \to \pi\, h_c$ decays of η_c & h_c	
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$	
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ (PWA) $Zc(4020) \to \pi h_c$ $Zcs(3985) \to DsD^*$	> 2 at E_{cm}
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872)$ $X(3872) \to \pi\chi_{c1}$ $X(3872) \to DD^*$	
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(2317)$ $ee \to DsD(^*)K$	> 3 fb
CHARMED BARYON SPECTROSCOPY	decays of the Λ_c	

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

PRL126, 102001 (2021)



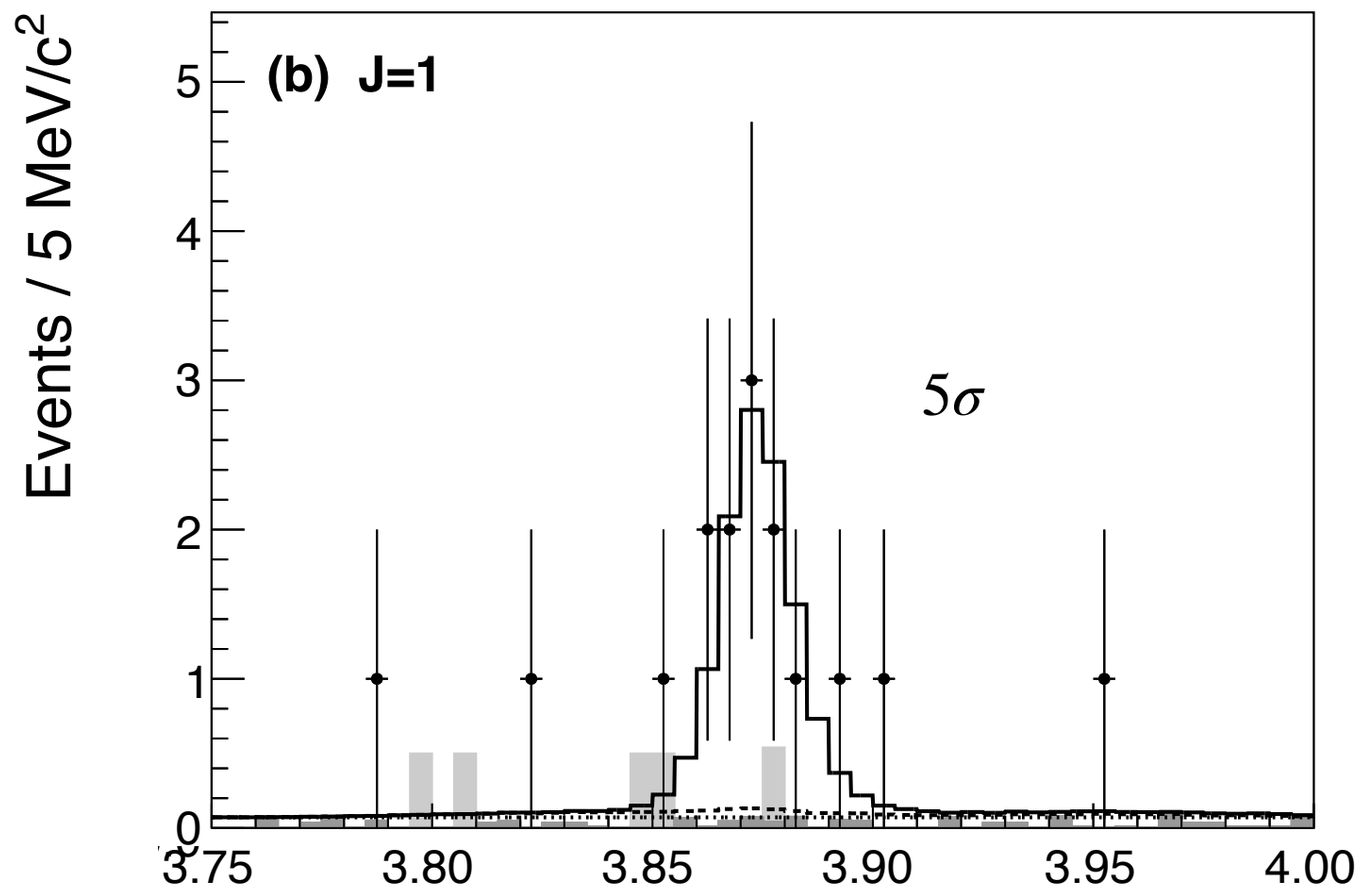
$\Longrightarrow$ *The isospin-1/2 $Z_{cs}(3985)$ appears near D_sD^* threshold.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT	PROSPECTS	FUTURE
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$			
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$			
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma + c\bar{c}$ $\psi(2S) \to \pi\, h_c$ decays of η_c &			
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$			E:
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ $Zc(4020) \to \pi h$ $Zcs(3985) \to Ds$			
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872$ $X(3872) \to \pi\chi$ $X(3872) \to DD$			
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(23$ $ee \to DsD(*)K$			ade);
CHARMED BARYON SPECTROSCOPY	decays of the Λ_c		access to the Σ_c, Ξ_c, Ω_c (and excitations), and possibly the P_c	and expanded energy reach into new territory

$X(3872) \to \pi^0\chi_{c1}$

PRL122, 202001 (2019)



$\Longrightarrow$ *BESIII can probe novel decay modes of the X(3872).*

Hadron Spectroscopy at the BESIII Experiment

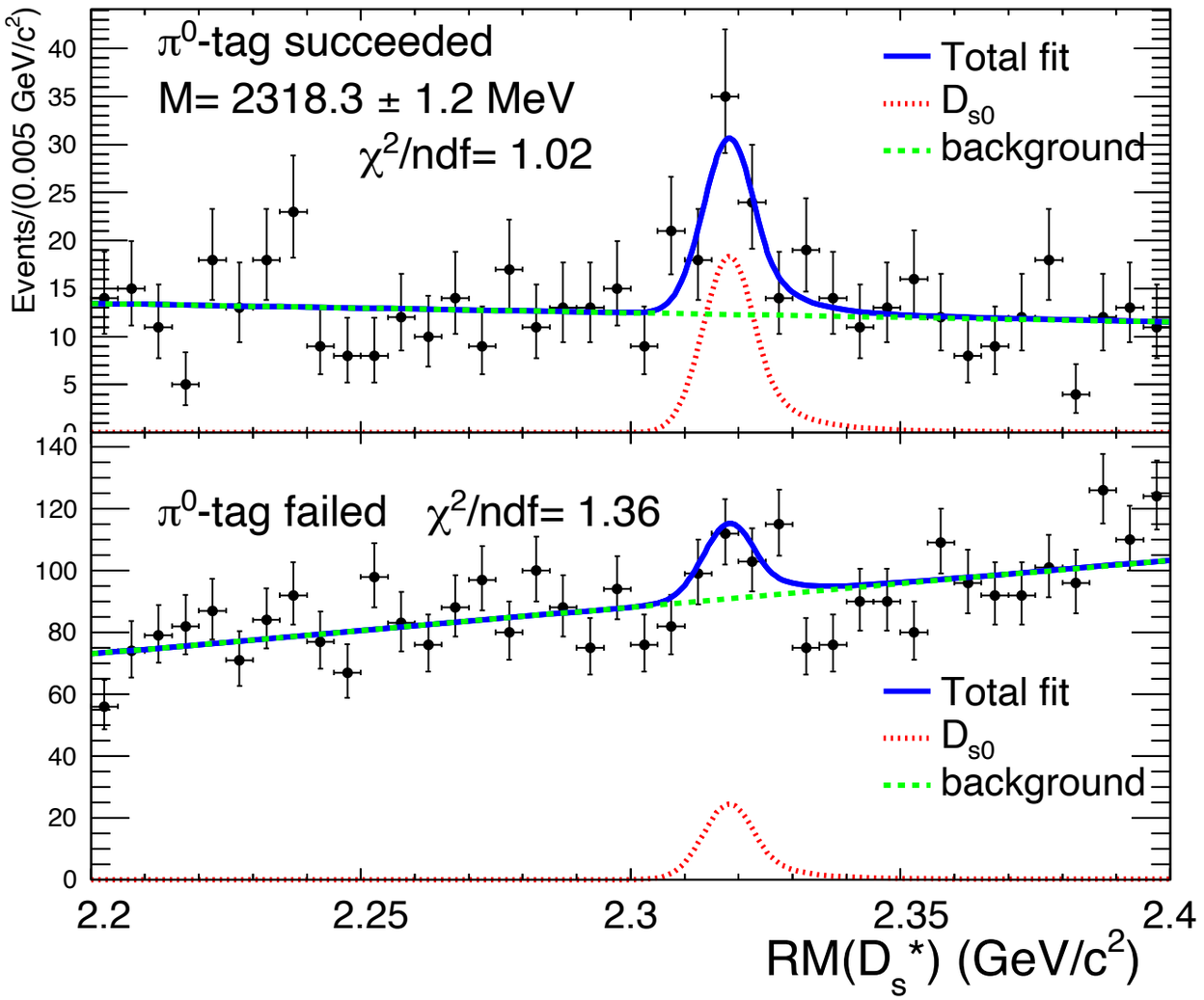
TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	10 billion J/ψ decays	*glueballs, hybrids, coupled-channel analyses*	no plans (analyze current data)
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$	2.7 billion $\psi(2S)$ decays	*further explorations in J/ψ, $\psi(2S)$, and other charmonium decays*	
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma + ccbar$ $\psi(2S) \to \pi h_c$ *decays of* η_c & h_c		*rare and precision transitions; properties of* ψ_2*; search for* η_{c2}…	
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$	> 20 fb^{-1} of data at E_{cm} above 4 GeV	*more data; coupled-channel analyses of* e^+e^- *cross sections*	BEPCII-U UPGRADE: (1) 3× luminosity for E_{cm} above 4 GeV (2) maximum energy increase from 5 to 5.6 GeV ⇒ much larger data sets above 4 GeV (plans are being made); and expanded energy reach into new territory
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ *(PWA)* $Zc(4020) \to \pi h_c$ $Zcs(3985) \to DsD^*$		*new* Z_c *and* Z_{cs} *decays;* E_{cm} *dependence; coupled-channels…*	
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872)$ $X(3872) \to \pi\chi_{c1}$ $X(3872) \to DD^*$		*increased precision and searches for new X(3872) decay modes*	
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(2317)$ $ee \to DsD(^*)K$	> 3 fb^{-1} above $\Lambda_c\Lambda_c$ threshold	*access to more D and* D_s *excited states*	
CHARMED BARYON SPECTROSCOPY	*decays of the* Λ_c		*access to the* Σ_c, Ξ_c, Ω_c *(and excitations), and possibly the* P_c	

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	*J/ψ →* *J/ψ →* *J/ψ →*			data)
LIGHT BARYON SPECTROSCOPY	*ψ(2S)* *ψ(2S)* *ψ(2S) →*			
CHARMONIUM SPECTROSCOPY	*ψ(2S) →* *ψ(2S)* *decays o*			
"Y" MESON SPECTROSCOPY	*ee →* *ee → π* *ee →*			ADE:
"Z" MESON SPECTROSCOPY	*Zc(3900) —* *Zc(402(* *Zcs(3985)*			sity GeV
"X" MESON SPECTROSCOPY	*ee → γ* *X(3872)* *X(3872)*			nergy n V
CHARMED MESON SPECTROSCOPY	*ee → Ds** *ee → D*			data eV made);
CHARMED BARYON SPECTROSCOPY	*decays of the*		*and possibly the P_c*	energy to new territory

$e^+e^- \to D_s^{*+}D_{s0}^{*-}(2317)$ + c.c. (500 pb^{-1} at 4.6 GeV)

PRD97, 051103 (2018)



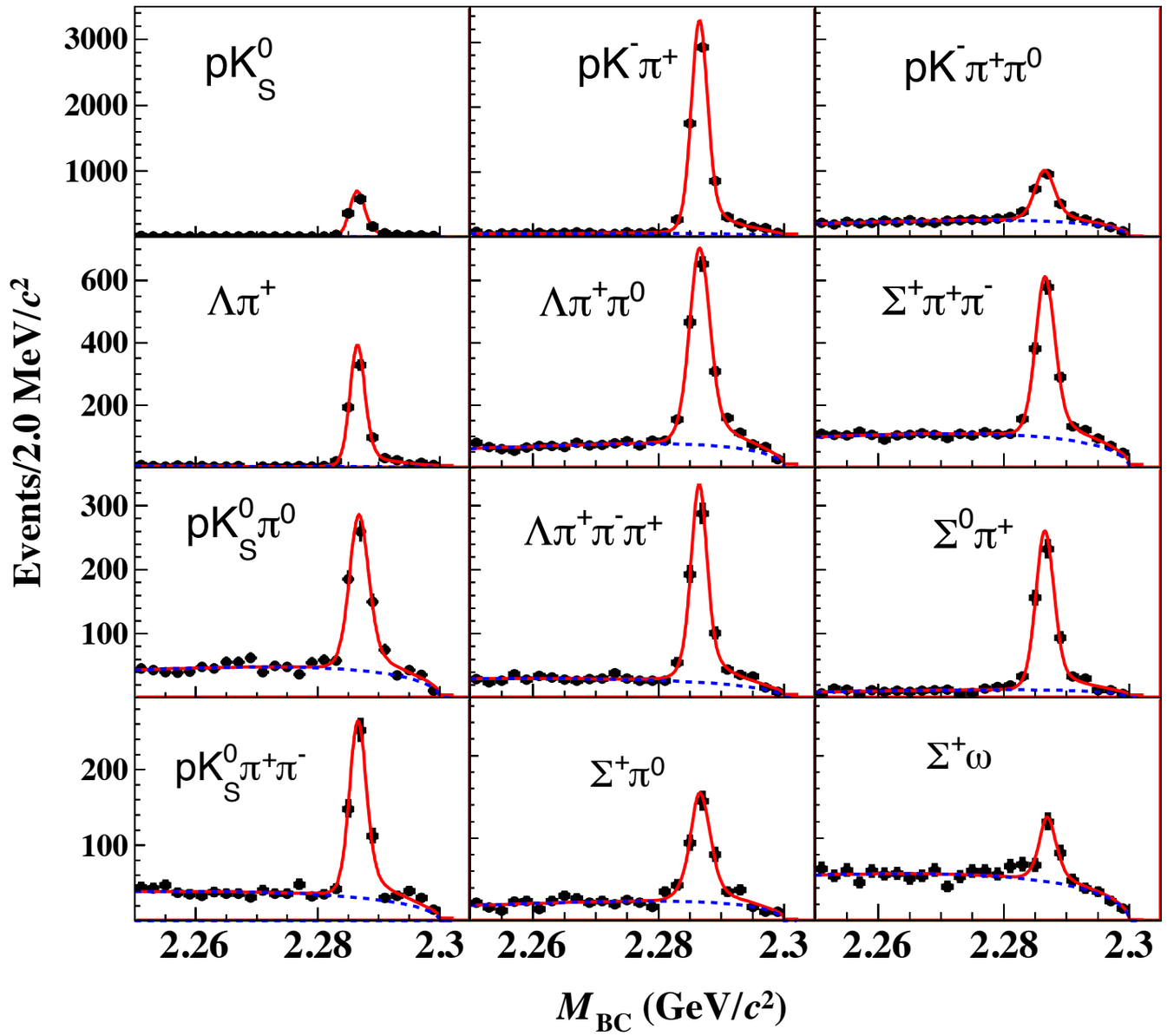
⟹ *Excited D_s states are produced with higher-energy e^+e^- collisions.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEME
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\pi$ $J/\psi \to \gamma\eta$
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to p$ $\psi(2S) \to p$ $\psi(2S) \to \Lambda$
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma +$ $\psi(2S) \to \pi$ decays of η_c
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J$ $ee \to \pi\pi\psi($ $ee \to D^*D$
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J$ $Zc(4020) \to$ $Zcs(3985) \to$
"X" MESON SPECTROSCOPY	$ee \to \gamma X(38$ $X(3872) \to$ $X(3872) \to$
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*$ $ee \to DsD($
CHARMED BARYON SPECTROSCOPY	decays of the

$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ (500 pb^{-1} at 4.6 GeV)

PRL116, 052001 (2016)



$\Longrightarrow$ *BESIII can study a wide variety of Λ_c decays. With higher energies, more charmed baryons will be accessible.*

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/\psi \to \gamma\eta\eta'$	10 billion J/ψ decays	*glueballs, hybrids, coupled-channel analyses*	no plans (analyze current data)
LIGHT BARYON SPECTROSCOPY	$\psi(2S) \to pp\pi$ $\psi(2S) \to pp\eta$ $\psi(2S) \to \Lambda\Sigma\pi$	2.7 billion $\psi(2S)$ decays	*further explorations in J/ψ, $\psi(2S)$, and other charmonium decays*	
CHARMONIUM SPECTROSCOPY	$\psi(2S) \to \gamma$ + ccbar $\psi(2S) \to \pi h_c$ decays of η_c & h_c		*rare and precision transitions; properties of ψ_2; search for η_{c2}…*	
"Y" MESON SPECTROSCOPY	$ee \to \pi\pi J/\psi$ $ee \to \pi\pi\psi(2S)$ $ee \to D^*D^*$	> 20 fb^{-1} of data at E_{cm} above 4 GeV	*more data; coupled-channel analyses of e^+e^- cross sections*	BEPCII-U UPGRADE: (1) 3× luminosity for E_{cm} above 4 GeV (2) maximum energy increase from 5 to 5.6 GeV ⇒ much larger data sets above 4 GeV (plans are being made); and expanded energy reach into new territory
"Z" MESON SPECTROSCOPY	$Zc(3900) \to \pi J/\psi$ *(PWA)* $Zc(4020) \to \pi h_c$ $Zcs(3985) \to DsD^*$		*new Z_c and Z_{cs} decays; E_{cm} dependence; coupled-channels…*	
"X" MESON SPECTROSCOPY	$ee \to \gamma X(3872)$ $X(3872) \to \pi\chi_{c1}$ $X(3872) \to DD^*$		*increased precision and searches for new X(3872) decay modes*	
CHARMED MESON SPECTROSCOPY	$ee \to Ds^*Ds^*(2317)$ $ee \to DsD(^*)K$	> 3 fb^{-1} above $\Lambda_c\Lambda_c$ threshold	*access to more D and D_s excited states*	
CHARMED BARYON SPECTROSCOPY	decays of the Λ_c		*access to the Σ_c, Ξ_c, Ω_c (and excitations), and possibly the P_c*	

Hadron Spectroscopy at the BESIII Experiment

TOPIC	EXAMPLE ACHIEVEMENTS	CURRENT DATA SETS	PROSPECTS	FUTURE DATA SETS
LIGHT MESON SPECTROSCOPY	$J/\psi \to \gamma\pi\pi\eta'$ $J/\psi \to \gamma\pi\pi$ $J/$	10 billion $J/$	*glueballs, hybrids, coupled-channel*	no plans (analyze current data)
LIGHT BARYON SPECTROSCOPY			*s* *her* *s*	
CHARMONIUM SPECTROSCOPY	$\psi($ *de*		*es* ...	
"Y" MESON SPECTROSCOPY			*f*	BEPCII-U UPGRADE:
"Z" MESON SPECTROSCOPY	$Zc(3$ Z Zcs		*s;*	(1) 3× luminosity for E_{cm} above 4 GeV
"X" MESON SPECTROSCOPY	e X $X($		*w* *es*	(2) maximum energy increase from 5 to 5.6 GeV
CHARMED MESON SPECTROSCOPY	$ee \to$ $ee \to D\bar{D}(\ldots)$	threshold	*and* *states*	⇒ much larger data sets above 4 GeV (plans are being made); and expanded energy reach into new territory
CHARMED BARYON SPECTROSCOPY	*decays of the* Λ_c		*access to the* Σ_c, Ξ_c, Ω_c *(and excitations), and possibly the* P_c	

For many more details, see:

(1) the BESIII Snowmass white paper:

"Physics in the tau-charm Region at BESIII"
arXiv:2204.08943

(2) a white paper on the BESIII physics program:

"Future Physics Programme of BESIII"
CPC44, 040001 (2020)
arXiv:1912.05983