$Z_{cs}(3985)$ and Z_c studies at BESIII

Ziyi Wang

***University of Chinese Academy of Sciences* (UCAS)**

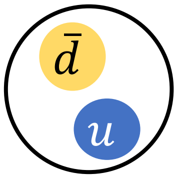
(On behalf of the BESIII collaboration)

Outline

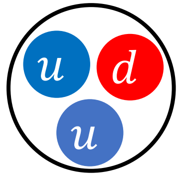
- **Brief look on charmonium spectrum**
- **Introduction to BEPCII and BESIII**
- **Recent results on Z_{cs} and Z_c states**
- **Summary**

Hadrons and Exotic Hadrons

Conventional hadrons

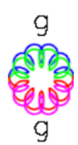


Meson

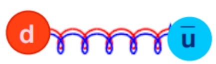


Baryon

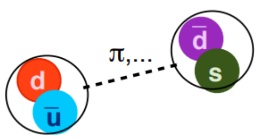
Exotic hadrons



Glueball



Hybrid

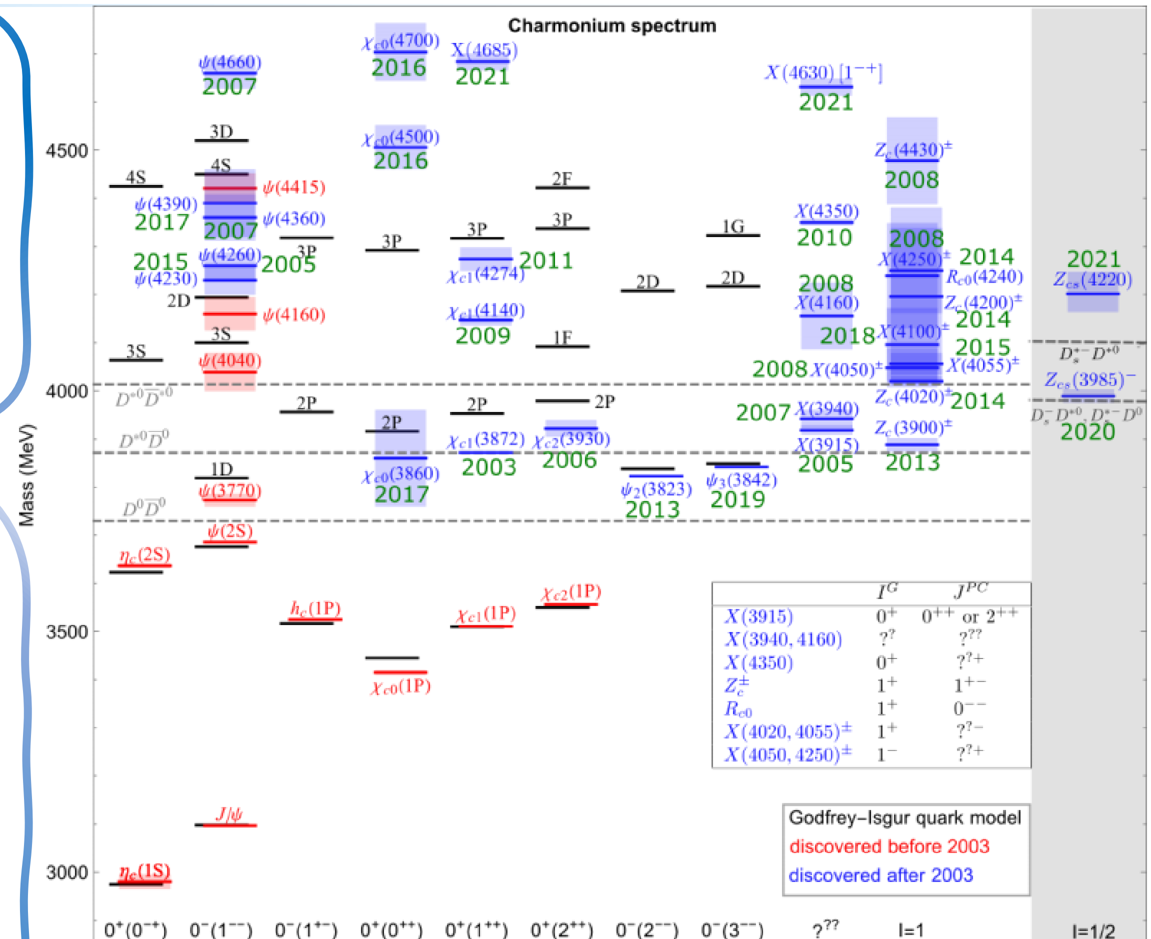


Molecule

Tetraquark

Pentaquark

and …



- ✓ **Overpopulated observed new charmonium-like states, i.e. "XYZ".**
- ✓ **Most of them are close to the mass thresholds of charmed meson pairs.**

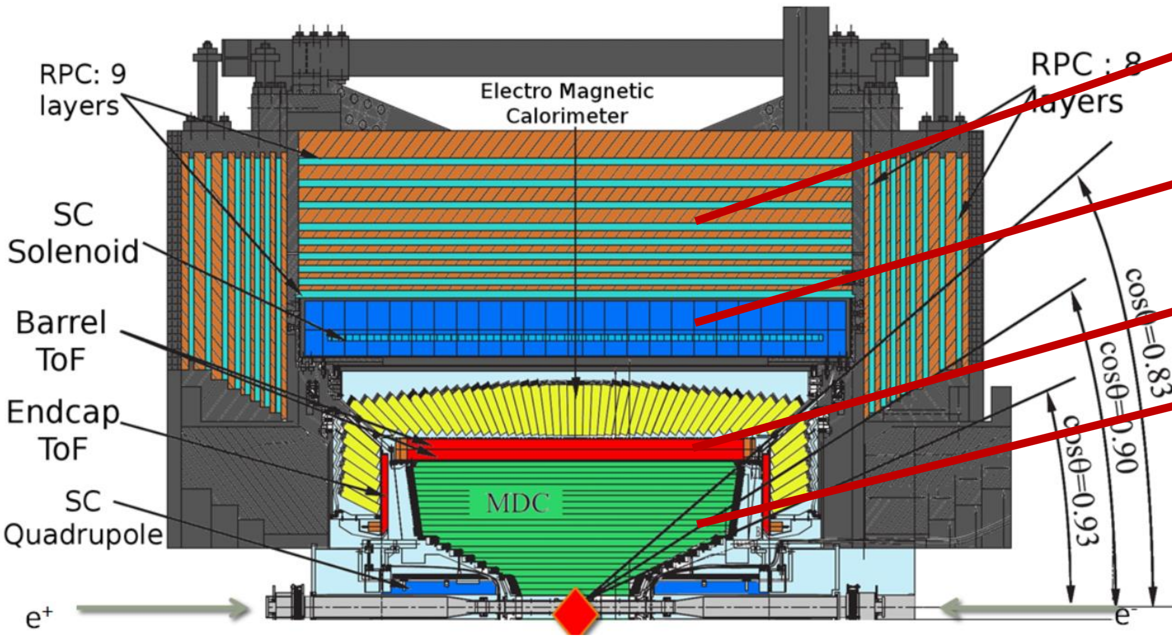
Overview of the Current $Z_{c(s)}$ States

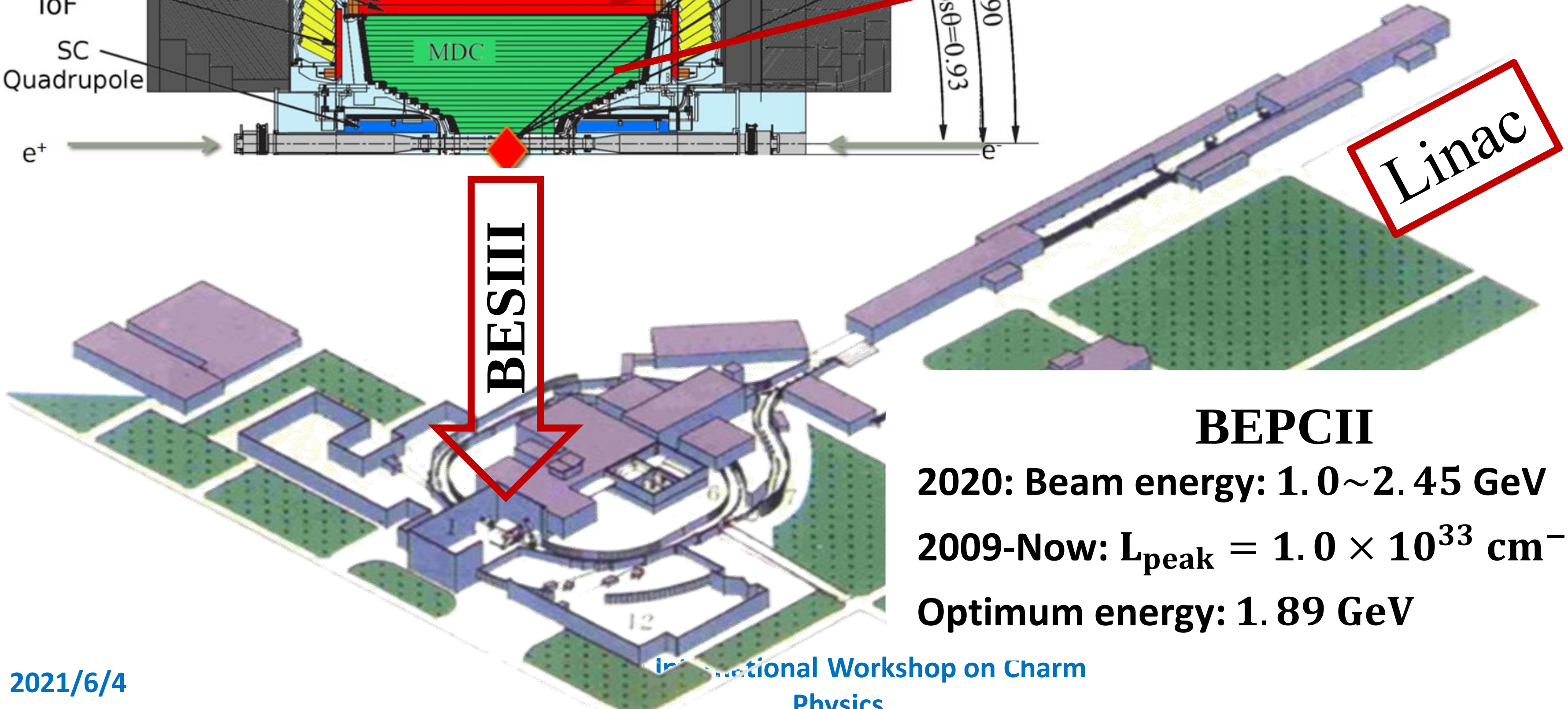
State	M (MeV/c^2)	Γ (MeV)	J^{PC}	Process	Experiment
$Z_c(3900)^{(\pm,0)}$	3888.4 ± 2.5	28.3 ± 2.5	1^{+-}	$e^+e^- \to \pi^{(+,0)}(\pi^{(-,0)} J/\psi)$	BESIII, Belle
				$e^+e^- \to \pi^{(+,0)}(D\bar{D}^*)^{(-,0)}$	BESIII
				$H_b \to X\pi^+(\pi^- J/\psi)$	D0
				$e^+e^- \to \pi^+(\eta_c \rho^-)$	BESIII
$Z_c(4020)^{(\pm,0)}$	4024.1 ± 1.9	13 ± 5	$1^{+-}(?)$	$e^+e^- \to \pi^{(+,0)}(\pi^- h_c)$	BESIII, Belle
				$e^+e^- \to \pi^{(+,0)}(D^*\bar{D}^*)^{(-,0)}$	BESIII
$Z(4050)^\pm$	4051^{+24}_{-40}	82^{+50}_{-28}	$??^{+}$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle
$Z(4055)^\pm$ 3.5σ	4054 ± 3.2	45 ± 13	$??^{-}$	$e^+e^- \to \pi^+(\pi^-\psi(2S))$	Belle
$Z(4100)^\pm$ 3.4σ	4096 ± 28	152^{+80}_{-70}	$??^{?}$	$B^0 \to K^+(\pi^-\eta_c)$	LHCb
$Z(4200)^\pm$	4196^{+35}_{-32}	370^{+100}_{-150}	1^{+-}	$\bar{B}^0 \to K^-(\pi^+ J/\psi)$	Belle, LHCb
$Z(4250)^\pm$	4248^{+190}_{-50}	177^{+320}_{-70}	$??^{+}$	$\bar{B}^0 \to K^-(\pi^+\chi_{c1})$	Belle
$Z(4430)^\pm$ first/2008	4478^{+15}_{-18}	181 ± 31	1^{+-}	$B^0 \to K^+(\pi^-\psi(2S))$	Belle, LHCb
				$\bar{B}^0 \to K^-(\pi^+ J/\psi)$	Belle
$R_{c0}(4240)$	4239^{+50}_{-21}	220^{+120}_{-90}	0^{--}	$B^0 \to K^+\pi^-\psi(2S)$	LHCb
$Z_{cs}(3985)^\pm$	$3982.5^{+2.8}_{-3.4}$	$12.8^{+6.1}_{-5.3}$	?	$e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$	BESIII
$Z_{cs}(4000)^\pm$	4003^{+7}_{-15}	131 ± 30	1^+	$B^+ \to \phi(J/\psi K^+)$	LHCb
$Z_{cs}(4220)^\pm$	4216^{+49}_{-38}	233^{+110}_{-90}	1^+	$B^+ \to \phi(J/\psi K^+)$	LHCb

- ✓ Produced in $\boldsymbol{e^+e^-}$ **annihilation** or ***b*-flavor hadron decays**.
- ✓ Typically, in $\boldsymbol{h + charmonium}$ final states.
- ✓ Intrinsic nature unclear, exotic states? kinematic effects?

Spin-parity, Argand plot?
Production mechanism?
Different decay modes?
Partner states?
Interference?

BEPCII and BESIII





BEPCII

2020: Beam energy: $1.0{\sim}2.45$ GeV

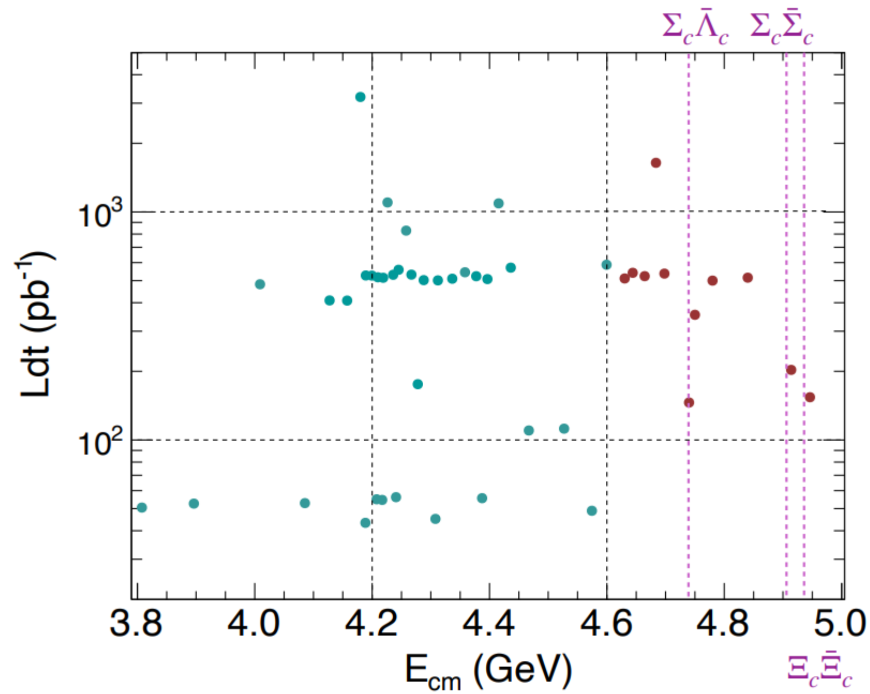
2009-Now: $L_{peak} = 1.0 \times 10^{33}\ cm^{-2}s^{-1}$

Optimum energy: 1.89 GeV

BESIII Data Samples

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

2020: 3.8 fb^{-1} scan 4.61-4.7 GeV
2021: 2 fb^{-1} scan 4.74-4.946 GeV



For 'XYZ' analyses

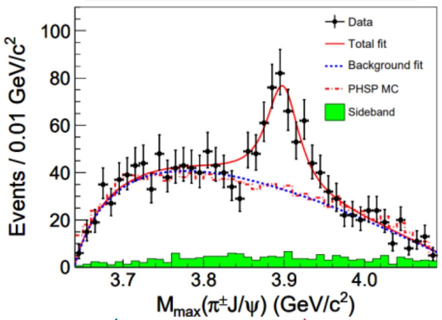
46 points above 3.8 GeV, L_{tot}~$21.9\ fb^{-1}$

29 energy points with $L_i > 0.4\ fb^{-1}$

Z_c Family at BESIII

$Z_c(3900)^+$

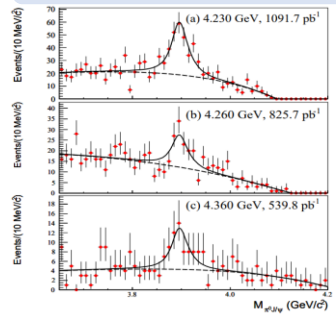
PRL 110, 252001 (2013)



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

$Z_c(3900)^0$

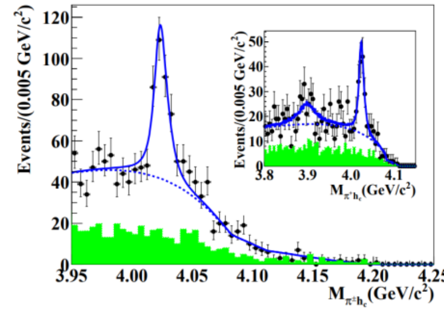
PRL 115, 112003 (2015)



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

$Z_c(4020)^+$

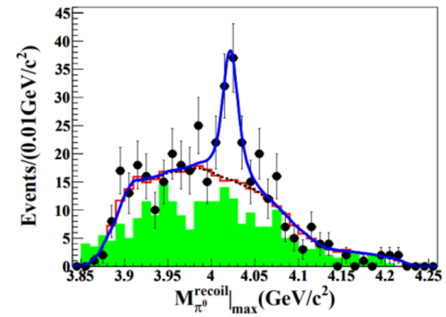
PRL 111, 242001 (2013)



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

$Z_c(4020)^0$

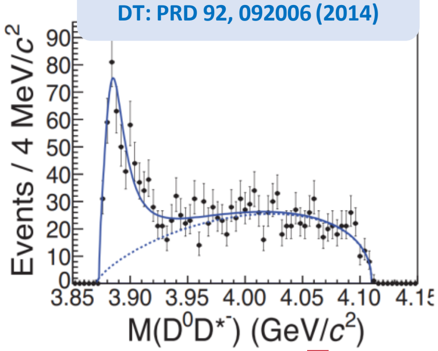
PRL 113, 212002 (2014)



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

$Z_c(3885)^+$

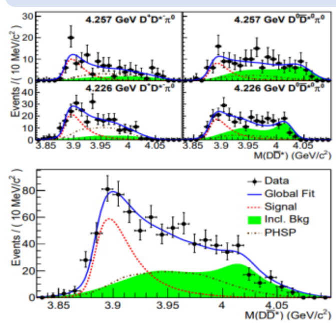
ST: PRL 112, 022001 (2014)
DT: PRD 92, 092006 (2014)



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

$Z_c(3885)^0$

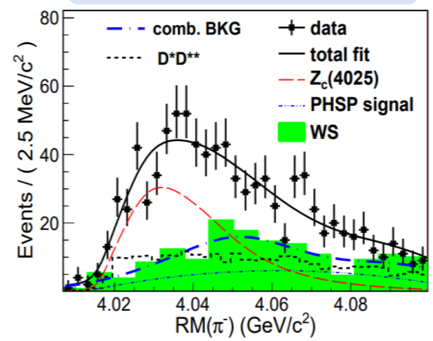
PRL 112, 022001 (2014)



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

$Z_c(4025)^+$

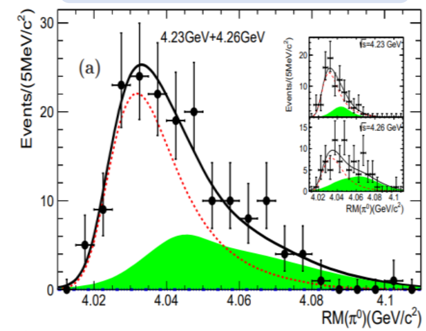
PRL 112, 132001 (2014)



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

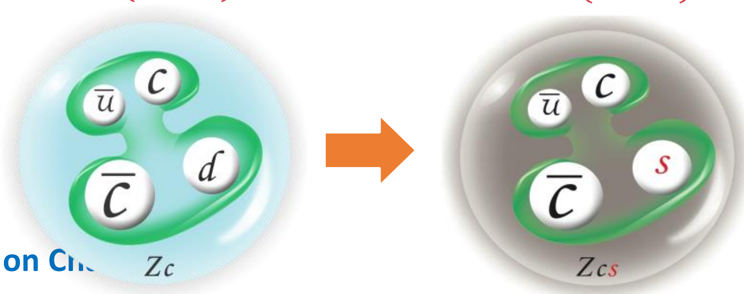
$Z_c(4025)^0$

PRL 115, 182002 (2015)



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

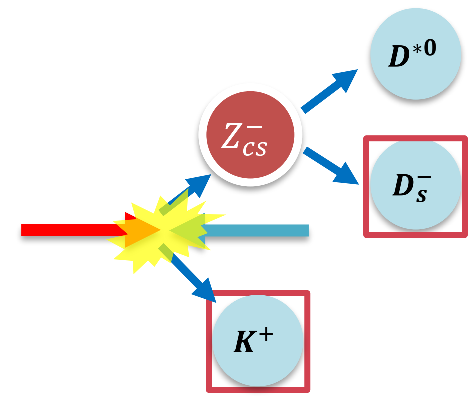
- ✓ What is the nature of these states?
- ✓ If exists, there should be SU(3) counter-part Z_{cs} state with strangeness.



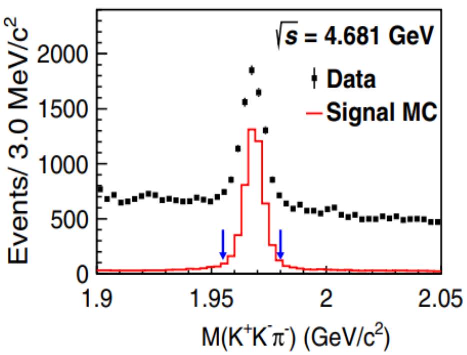
Observation of the charged $Z_{cs}(3985)^-$

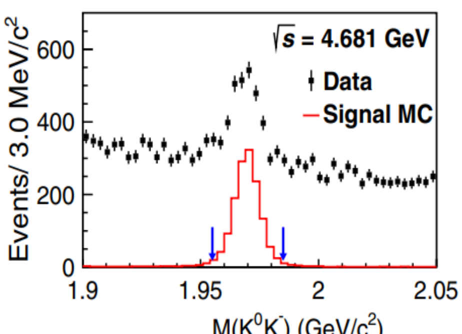
PRL 126, 102001 (2021)

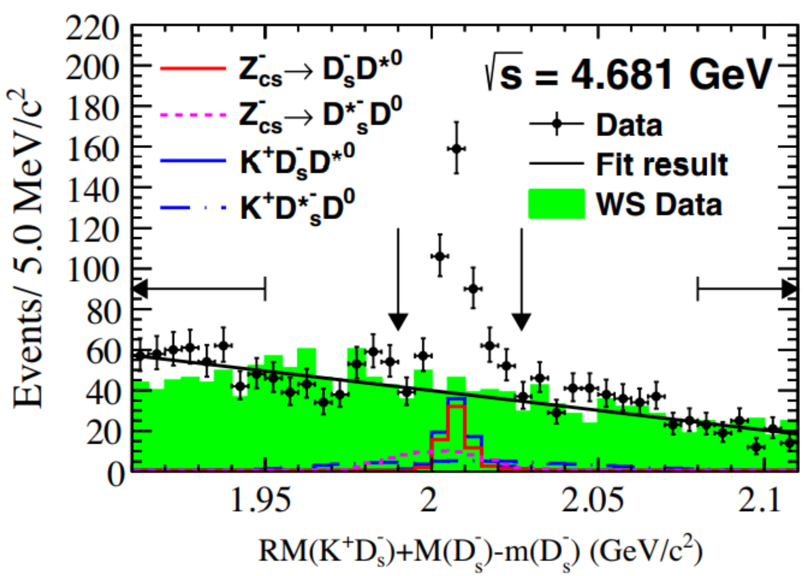
- $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$
  - ✓ 3.7fb^{-1} data accumulated at 4.628, 4.641, 4.661, 4.681 and 4.698GeV in 2020.
  - ✓ **Partial reconstruction of K^+ and D_s^-.**
  - ✓ Signature in the **recoil mass spectrum of $K^+D_s^-$** to identify the process of $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$.

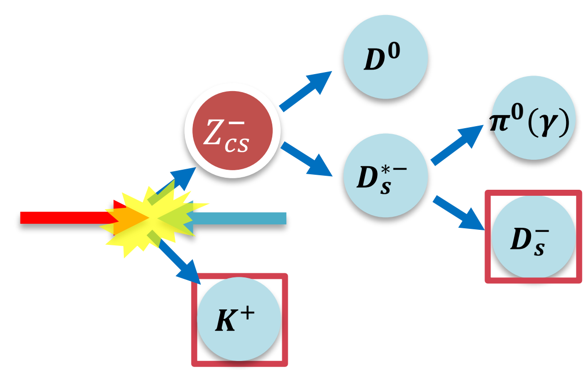


$e^+e^- \to K^+D_s^-D^{*0}$





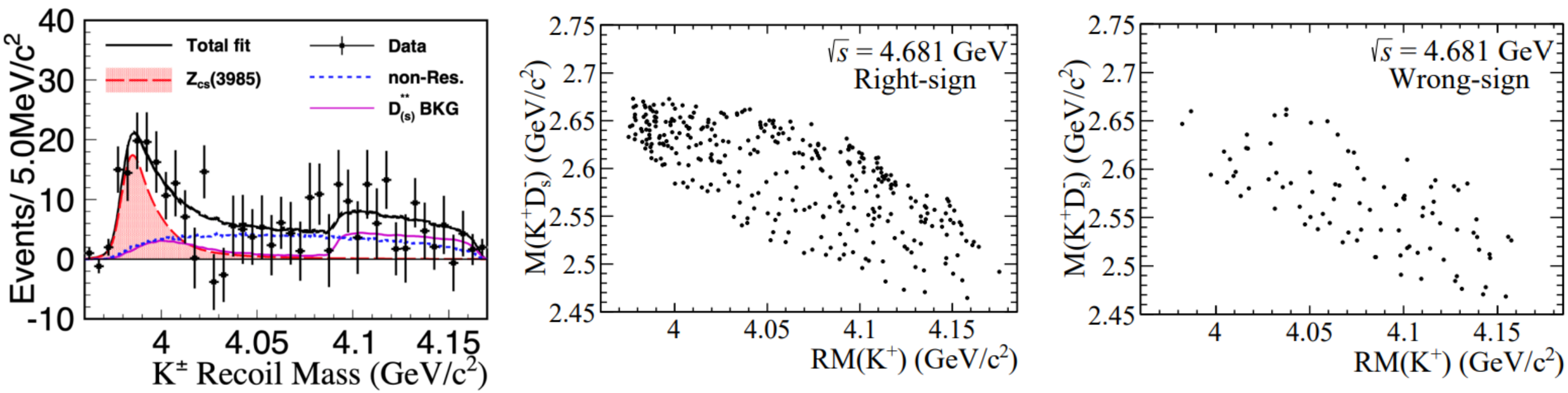




$e^+e^- \to K^+D_s^{*-}D^0$

Observation of the charged $Z_{cs}(3985)^-$

PRL 126, 102001 (2021)



✓ Conventional charmed mesons can not describe the enhancement below 4.0 GeV/c^2.

(With a sufficient study for all possible $D_{(s)}^{**}$ background and their interference effect, see Appendix.)

✓ 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:

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

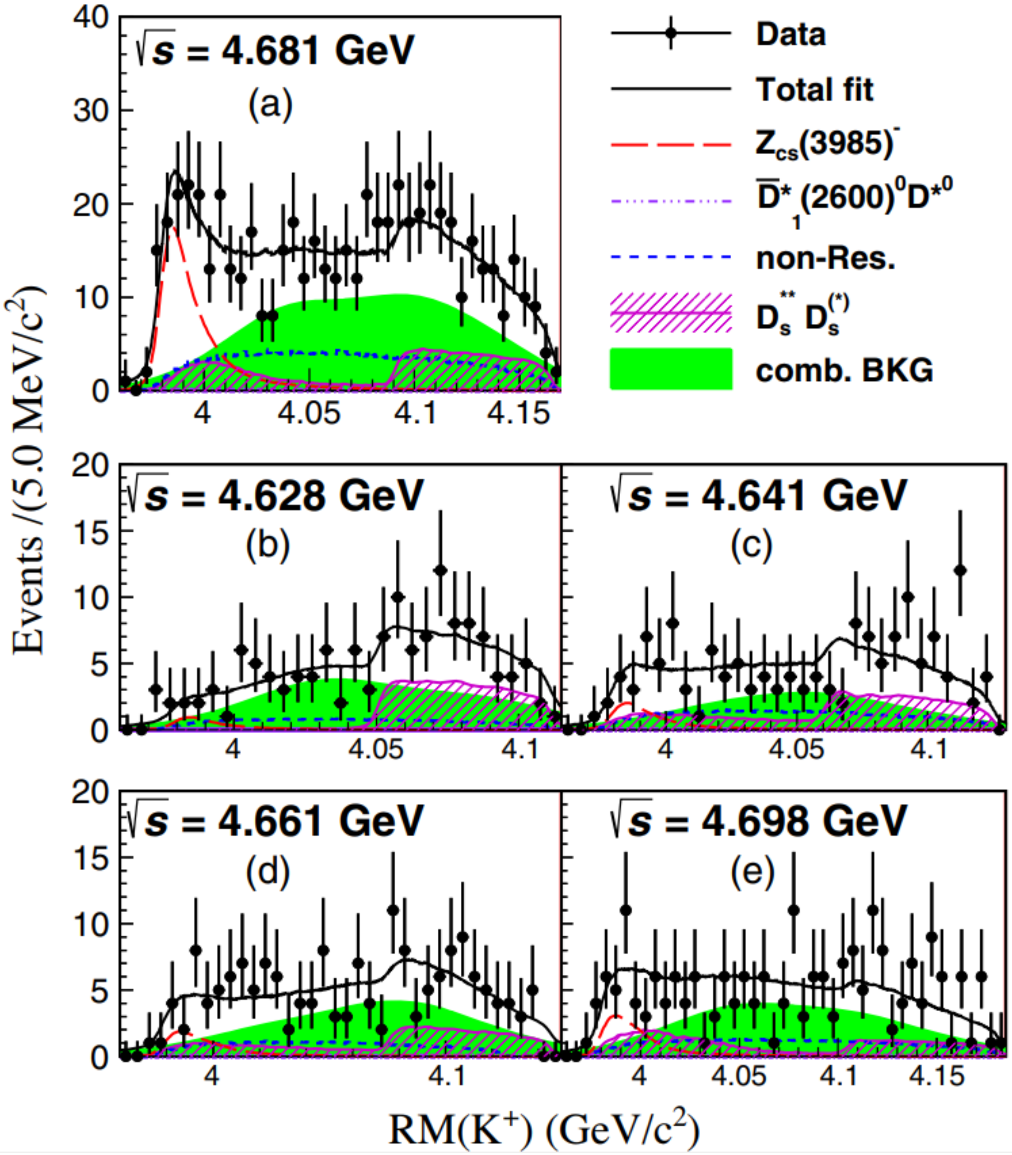
$$\boldsymbol{\Gamma = 13.8^{+8.1}_{-5.2} \pm 4.9\ \mathrm{MeV}}$$

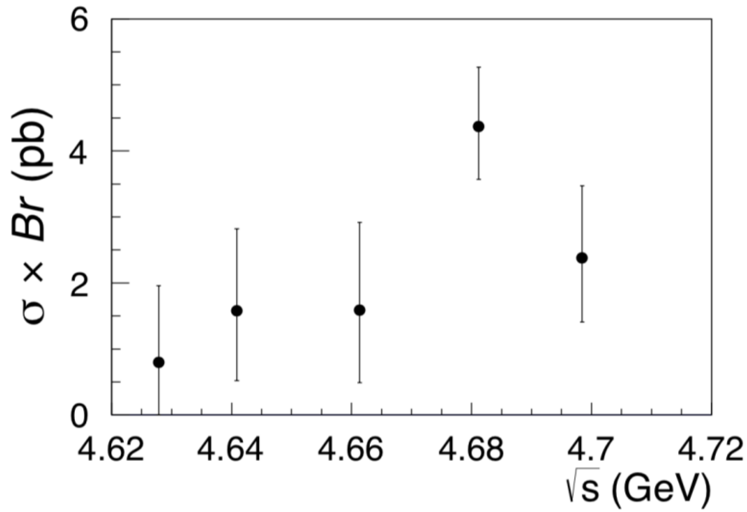
✓ Global significance: $> 5.3\ \sigma$

First candidate of the hidden-charm tetraquark with strangeness

Cross section of $Z_{cs}(3985)^-$ production

PRL 126, 102001 (2021)





- ✓ Simultaneous fit to the five energy points.
- ✓ Largest cross sections around 4.681 GeV.

The $Z_{cs}(3985)^-$ and $Z_c(3885)^-$

	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
$\sigma^{Born} \cdot \mathfrak{B}$ (pb)	$4.4^{+0.9}_{-0.8} \pm 1.4$	13.5±2.1±4.8	83.5±6.6±22.0

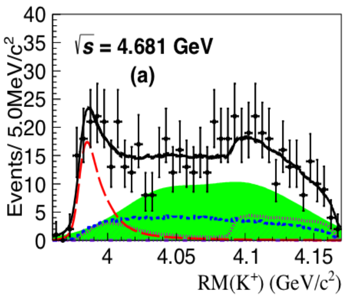
~10 MeV above D_sD^*/D_sD thresholds
similar to $Z_c(3900)$ & $Z_b(10,610)$
(DD*) (BB*)

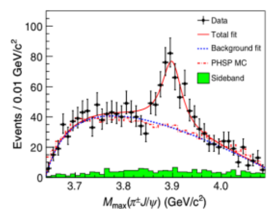
from Marek Karliner in Nov. 2020

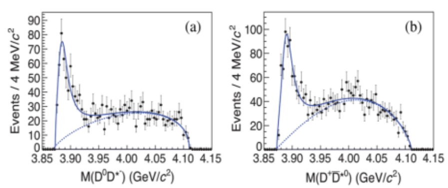
two general comments about
charm-tau factory program

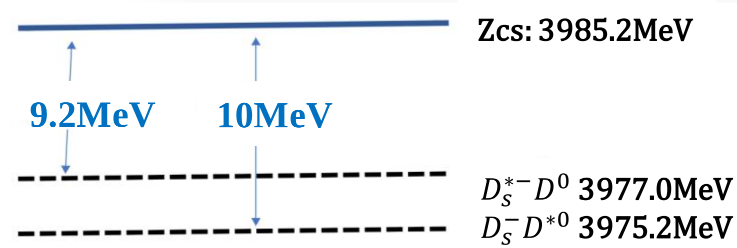
- $J/\psi K^{\pm}$ resonances:
  $Z_c(3900)$ analogue?
  $Z_c(3900)^+ = (c\bar{c}u\bar{d})$; $d \to s$: $(c\bar{c}u\bar{s}) \sim D_s\bar{D}^*$
  no natural molecular binding,
  so if discovered, would indicate
  Tq or a novel mechanism

SU(3) partner of Z_c (3900)?









$Z_{cs}(3985)$

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

neutral/charged = 1

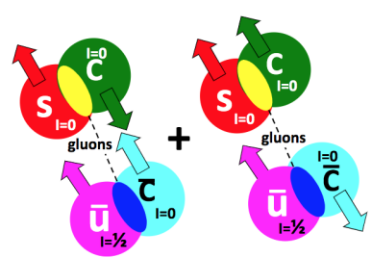
In process

$Z_c(3900)$

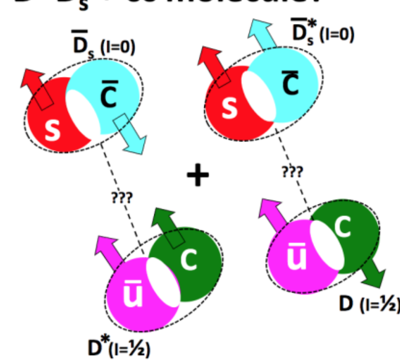
$\pi^- Z_c^+$	$\pi^0 Z_c^0$	$\pi^+ Z_c^-$
1/3	1/3	1/3

neutral/charged = 1/2

diquark-antidiquark?



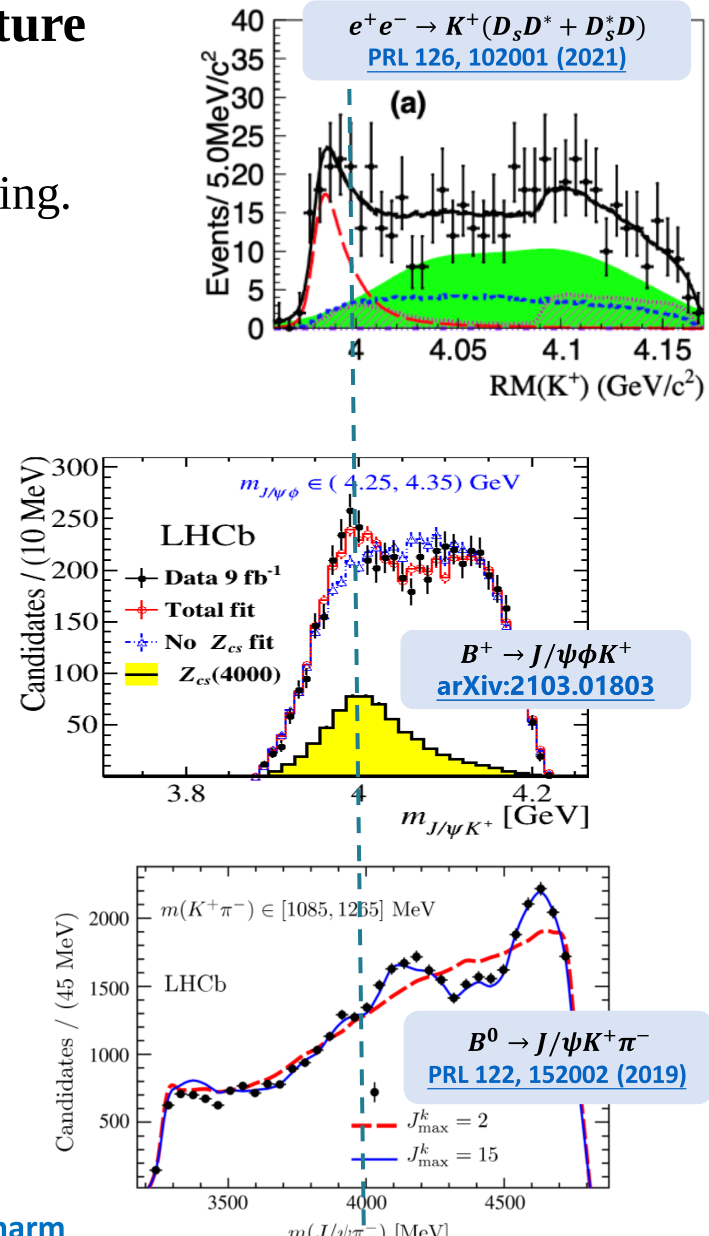
D*$\bar{D}_s$ + cc molecule?



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

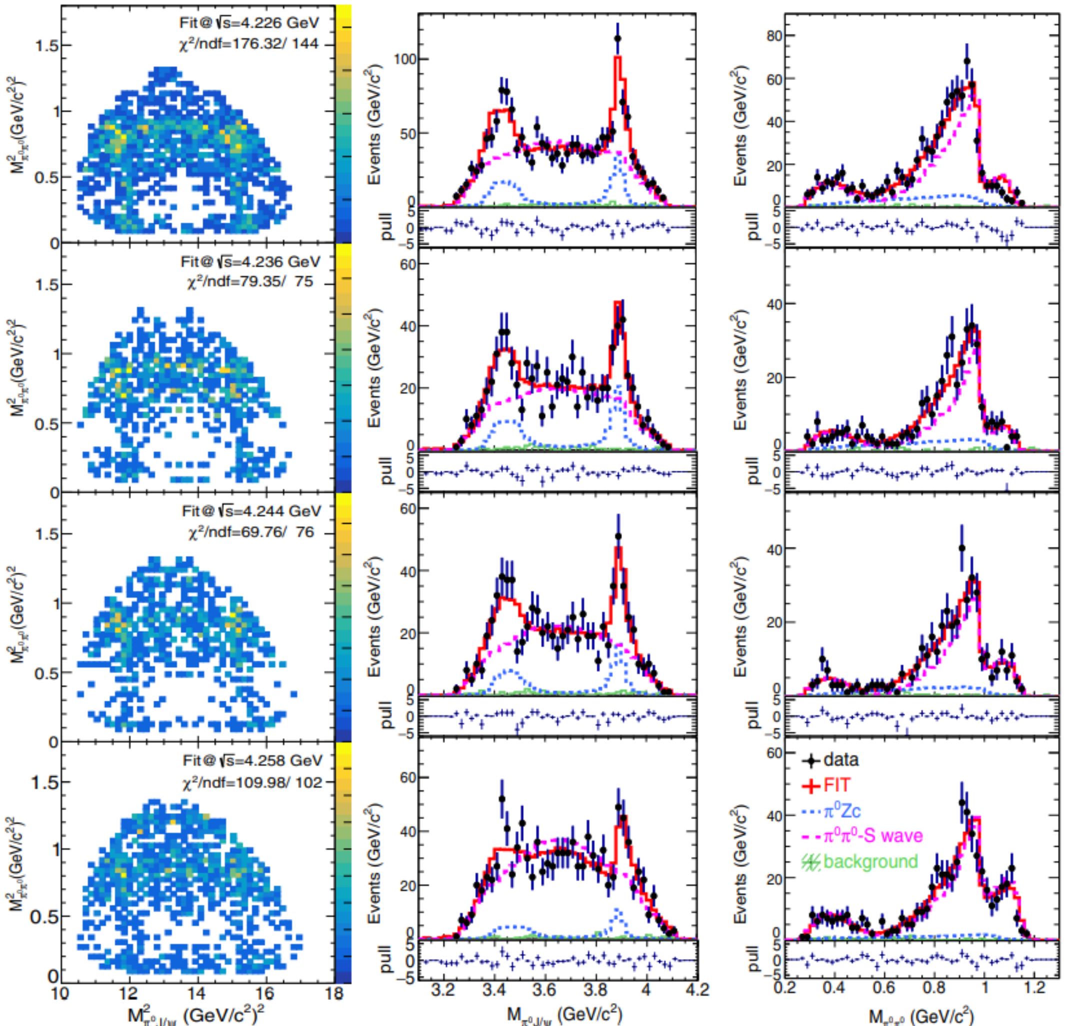
- **Various interpretations are possible for the structure**
  - ✓ Molecule.
  - ✓ $D_{s2}^*(2573)^+ D_s^{*-}$ threshold kinematic effects / reflecting.
  - ✓ Re-scattering / Triangle singularity.
  - ✓ Mixture of molecular and tetraquark.
  - ✓ …

- **$Z_{cs}(3985)$ 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 $Z_c(3900)$?
  - ✓ Looking for more channels will be useful.



PWA of the $Z_c(3900)^0$

PRD 102, 012009 (2020)



- ✓ Simultaneous PWA fit of $e^+e^-\to\pi^0\pi^0 J/\psi$ to the four energy points
- ✓ The spin-parity of $Z_c(3900)^0$ is determined to be 1^+
- ✓ The nominal fit includes the intermediate process $\sigma J/\psi$, $f(980)J/\psi$, $f(1370)J/\psi$ and π^0 $Z_c(3900)^0$.
- ✓ Mass and width of $Z_c(3900)^0$ is measured:

$$M(Z_c(3900)^0) = (3893.0 \pm 2.3 \pm 3.2)\ \mathrm{MeV}/c^2,$$
$$\Gamma(Z_c(3900)^0) = (44.2 \pm 5.4 \pm 8.3)\ \mathrm{MeV}.$$

Cross sections of $\pi^0 Z_c(3900)^0$ production

PRD 102, 012009 (2020)

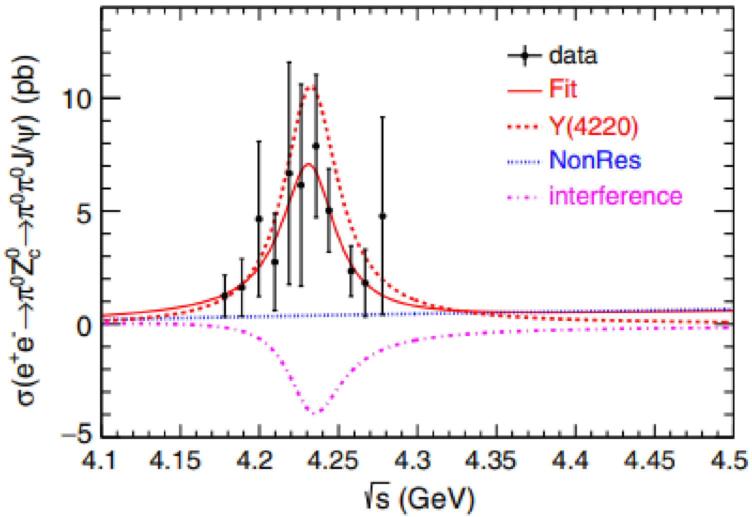


TABLE VI. Summary of the fit results to the measured cross sections of $e^+e^- \to \pi^0 Z_c(3900)^0 \to \pi^0\pi^0 J/\psi$. The uncertainties are statistical only.

Parameters	Solution I	Solution II
$p_0(c^2/\mathrm{MeV})$	0.0 ± 11.3	
p_1	$(1.8 \pm 1.9) \times 10^{-2}$	
$M(R)$ (MeV/c^2)	4231.9 ± 5.3	
$\Gamma_{\mathrm{tot}}(R))$ (MeV)	41.2 ± 16.0	
$\Gamma_{ee}\mathcal{B}_{R\to\pi^0 Z_c(3900)^0}$ (eV)	0.53 ± 0.15	0.22 ± 0.25
$\phi(R)$	$(-103.9 \pm 33.9)^\circ$	$(112.7 \pm 43.0)^\circ$

- ✓ Based on the PWA results, the Born cross sections for the process $e^+e^- \to \pi^0 Z_c(3900)^0 \to \pi^0\pi^0 J/\psi$ are measured.
- ✓ The parameters of Y- states are consistent with $Y(4220)$.

$$\boldsymbol{M = 4231.9 \pm 5.3 \pm 4.9\ \mathrm{MeV}/c^2, \Gamma = 41.2 \pm 16.0 \pm 16.4\ \mathrm{MeV}}$$

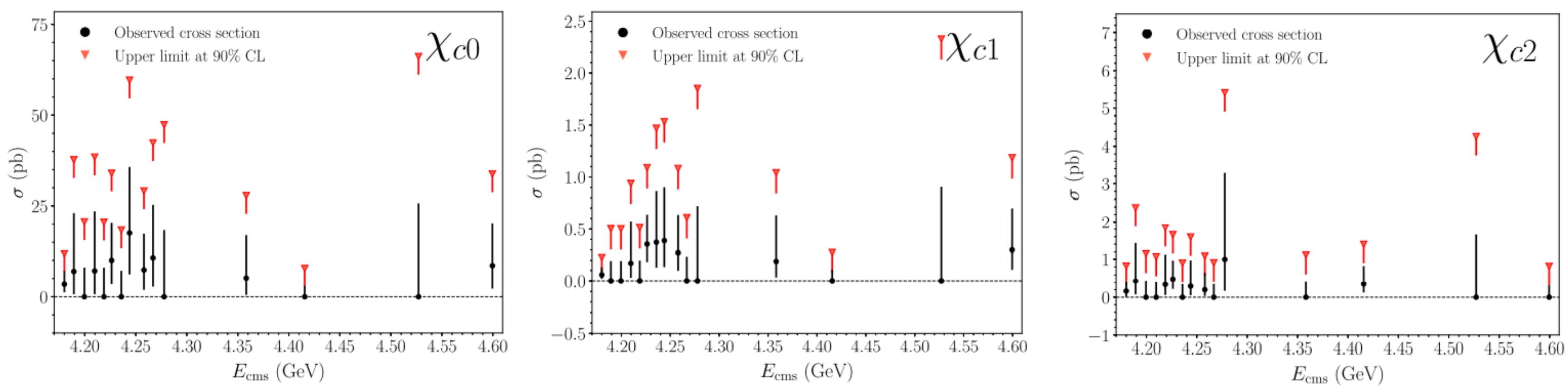
- ✓ **Establish the relationship between $Y(4220)$ and $Z_c(3900)^0$.**
- ✓ Due to the lack of data around 4.3 GeV, the existence of $Y(4230)$ in $Z_c(3900)^0$ production cannot be ruled out.

Search for $Z_c^+ \to \pi^+\chi_{cJ}$

PRD 103, 052010 (2021)

- ✓ Belle reported the results of $Z_c(4050)^+$ and $Z_c(4025)^+$ in $\bar{B}^0 \to K^- Z_c^+, Z_c^+ \to \pi^+\chi_{cJ}$ [PRD 78, 072004], while BaBar did not confirm them.
- ✓ BESIII studies $e^+e^- \to \pi^+\pi^-\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$ from 4.178 GeV to 4.600 GeV
- ✓ None of the process are observed and upper limits of the production cross sections are determined.
- ✓ Hence, they can be the upper limits of the product cross sections of

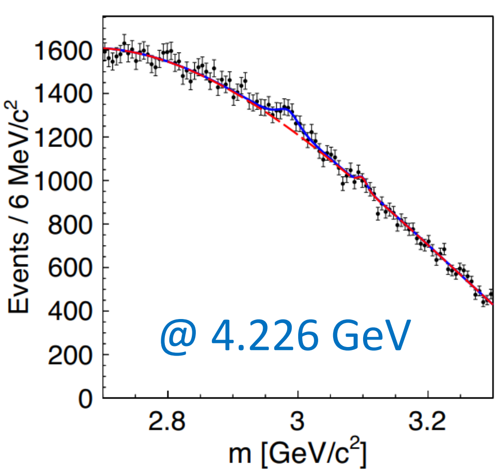
$$e^+e^- \to \pi^- Z_c(4050)^+ + c.c., Z_c(4050)^+ \to \pi^+\chi_{cJ}$$

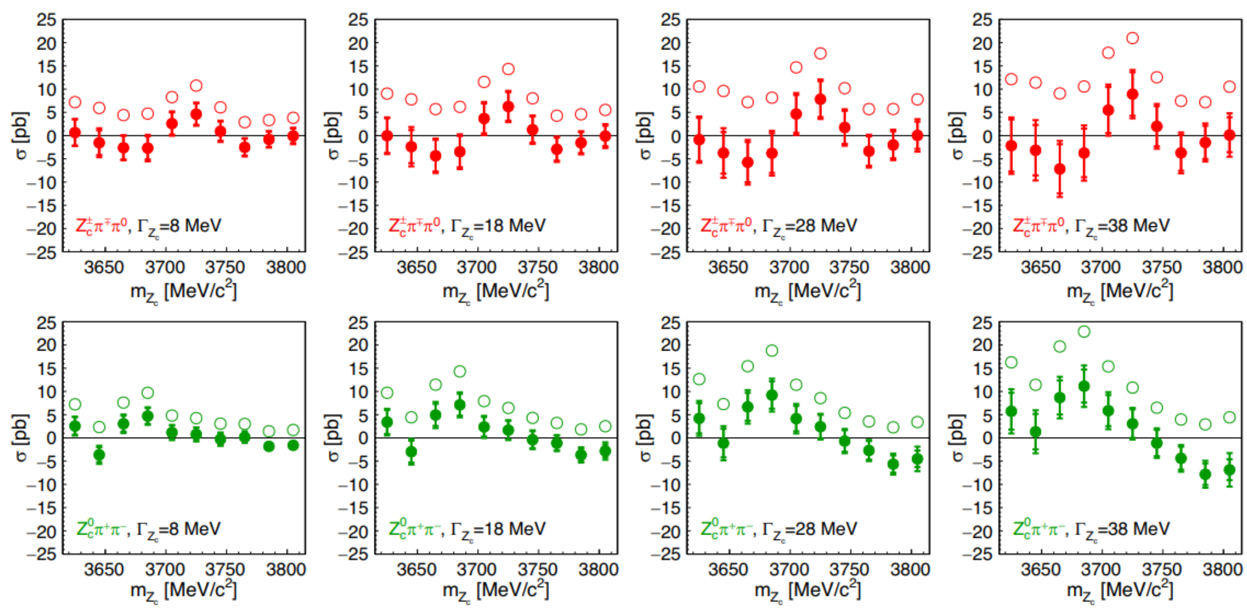


Search for $Z_c \to \pi\eta_c$

PRD 103, 032006 (2021)

- ✓ LHCb reported an evidence of $Z_c(4100)^+ \to \pi^+\eta_c$ in $\bar{B}^0 \to K^- Z_c(4100)^+$. with $M = 4096 \pm 20^{+18}_{-22}$ MeV/c^2, $\Gamma = 152 \pm 58^{+60}_{-35}$ MeV and $J^P = 0^+/1^-$. [EPJC 78 12, 1019]
- ✓ Studies of $e^+e^- \to \pi^+\pi^-\pi^0\eta_c, \pi^+\pi^-\eta_c, \gamma\pi^0\eta_c$ at 6 energy points from 4.178 GeV to 4.600 GeV.
- ✓ Only evidence of $\boldsymbol{e^+e^- \to \pi^+\pi^-\pi^0\eta_c}$ @ 4.226 GeV ($\boldsymbol{4.1\sigma}$).
- ✓ No significant for $Z_c \to \pi\eta_c$.
- ✓ Different mass and width assumptions in the vicinity of $D\bar{D}$ mass are tested for $Z_c^+ \to \pi^+\eta_c$ and $Z_c^0 \to \pi^0\eta_c$ in $e^+e^- \to \pi^+\pi^-\pi^0\eta_c$ @ 4.226 GeV and found to be not significant.



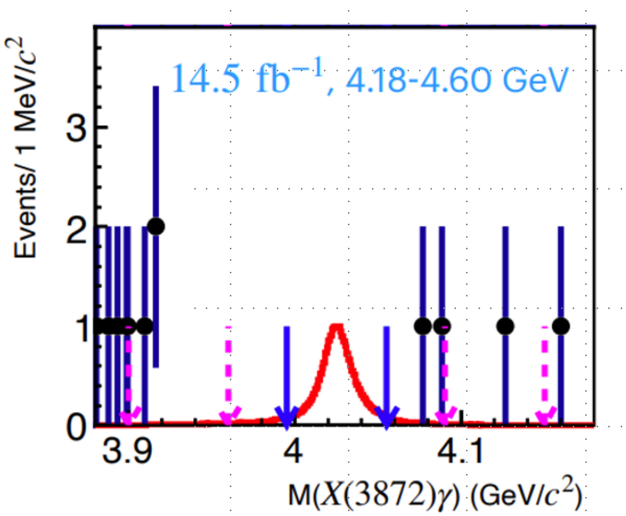


Search for $Z_c(4020) \to \gamma X(3872)$

arXiv: 2102.00644

- ✓ Connection between Z_c sates and X states in molecule picture.
- ✓ Branching fraction of $Z_c(4020)^0 \to \gamma X(3872)$ and $Z_c(4020)^\pm \to \pi^\pm X(3872)$ is quite different. [PRD 99, 054028]
- ✓ Studies of $e^+e^- \to \pi^0 X(3872)\gamma$ at center-of mass energies from 4.178 to 4.600 GeV.
- ✓ No significant signal for $e^+e^- \to \pi^0 Z_c(4020)^0, Z_c(4020)^0 \to \gamma X(3872)$:

$$\frac{\boldsymbol{\mathcal{B}[Z_c(4020)^0 \to \gamma X(3872)] \cdot \mathcal{B}[X(3872) \to \pi^+\pi^- J/\psi]}}{\boldsymbol{\mathcal{B}[Z_c(4020)^0 \to (D^*\bar{D}^*)^0]}} < \mathbf{0.24\%\ (@4.23\ GeV)}$$



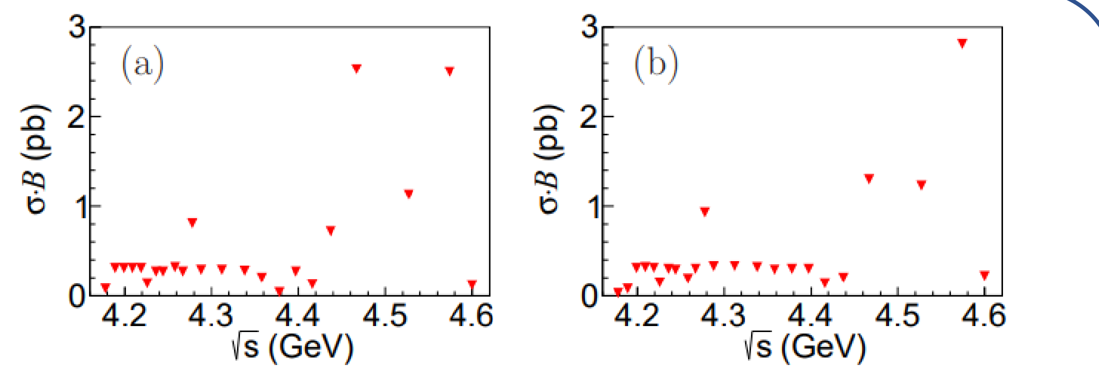


FIG. 2. The upper limits at the 90% C.L. on $\sigma(e^+e^- \to \pi^0 X(3872)\gamma) \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ (a) and $\sigma(e^+e^- \to \pi^0 Z_c(4020)^0) \cdot \mathcal{B}(Z_c(4020)^0 \to X(3872)\gamma) \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ (b) for each energy point.

Proposal of the upgrade BEPCII

- ✓ Following up with the beam energy and top-up upgrade, we are planning the next generation of upgrade BEPCII, to be implemented around 2022:
  the optimized energy is 2.35 GeV with luminosity 3 times higher than current BEPCII.
- ✓ 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.

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 right-most column shows the number of required data taking days with the current (T_C) and 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	$\Sigma_c^+\bar{\Lambda}_c^-$ 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

Future Physics Programme of BESIII [Chin.Phys.C 44, 040001 (2020)]

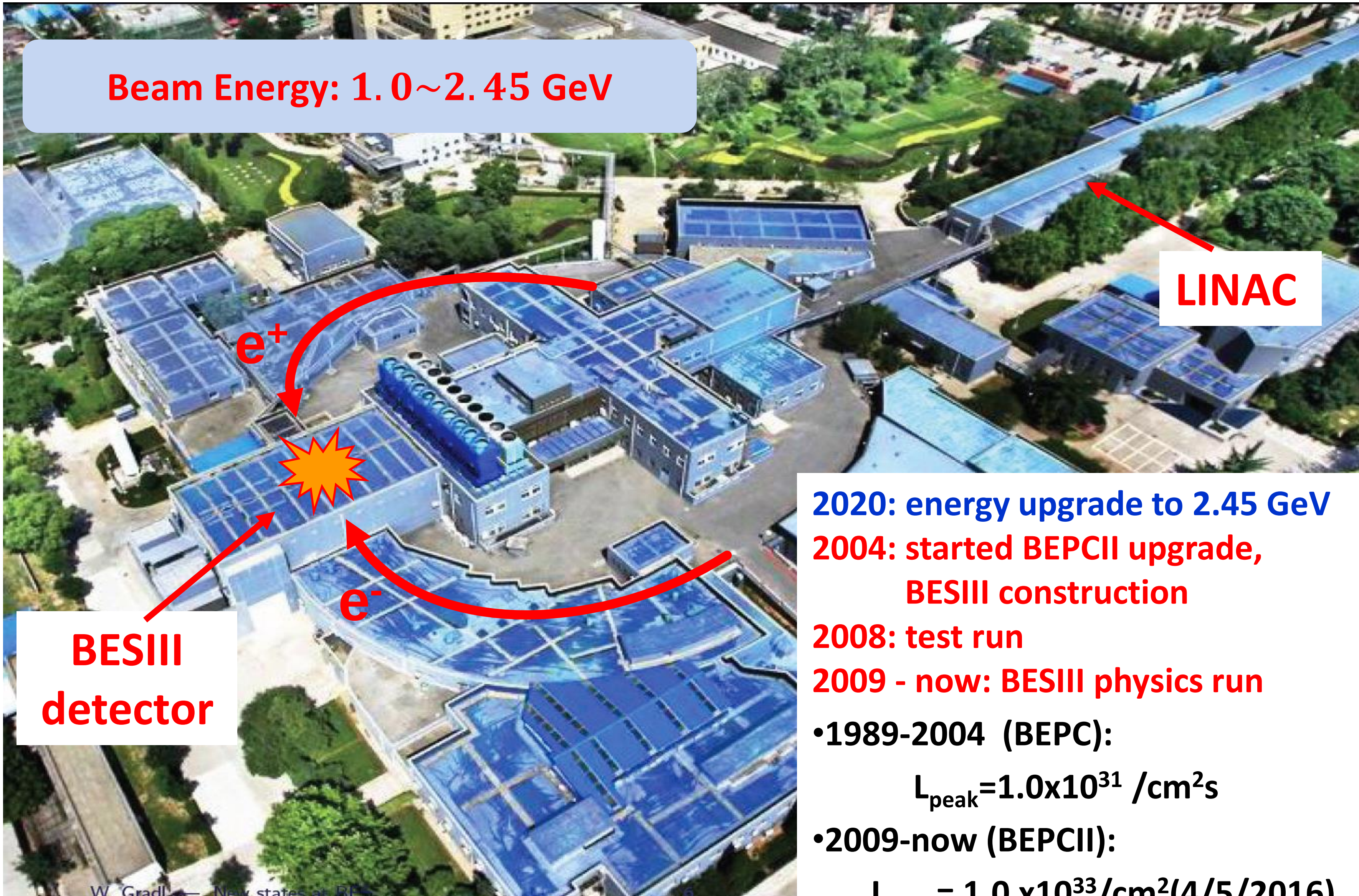
Summary

- **BESIII is successfully operating since 2008 and will continue to run for 5-10 years.**
- **Unique data samples from 3.8 GeV to 4.95 GeV. Many exciting results have been published covering many aspects on $Z_{c(s)}$ states.**
  - ✓ **Observation of the $Z_{cs}(3985)$**
  - ✓ **PWA on $Z_c(3900)$**
  - ✓ **More results about the production & decay of $Z_{c(s)}$, structure properties are in process**
- **Future on $Z_{c(s)}$ studies (looking forward to upgrade BEPCII): With high-luminosity, fine scan samples above 3.8 GeV, many programs deserver more dedicated effort.**

Thanks for your attention~

Backup

Appendix - Beijing Electron Positron Collider (BEPCII)



2020: energy upgrade to 2.45 GeV

2004: started BEPCII upgrade, BESIII construction

2008: test run

2009 - now: BESIII physics run

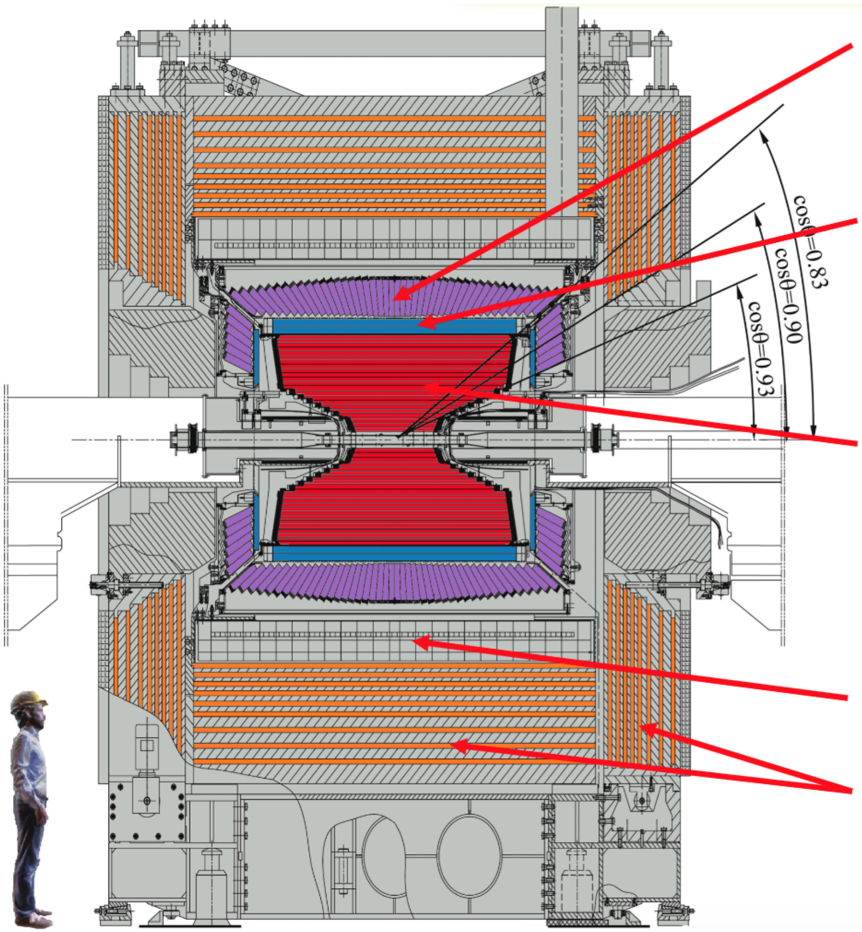
- **1989-2004 (BEPC):**

  L_{peak}=1.0x10^{31} /cm^{2}s

- **2009-now (BEPCII):**

  L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

Appendix - The BESIII Detector



EMC: CsI crystals
$\Delta E/E$ = 2.5% @ 1 GeV - Barrel
$\Delta E/E$ = 5.0% @ 1 GeV - Endcaps

TOF:
σ_T = 80 ps Barrel
σ_T = 110 (60) ps Endcap

MDC: small cell & He gas
σ_{xy}= 130 μm
σ_p/p = 0.5% @1GeV
dE/dx = 6%

Magnet: 1T Super conducting

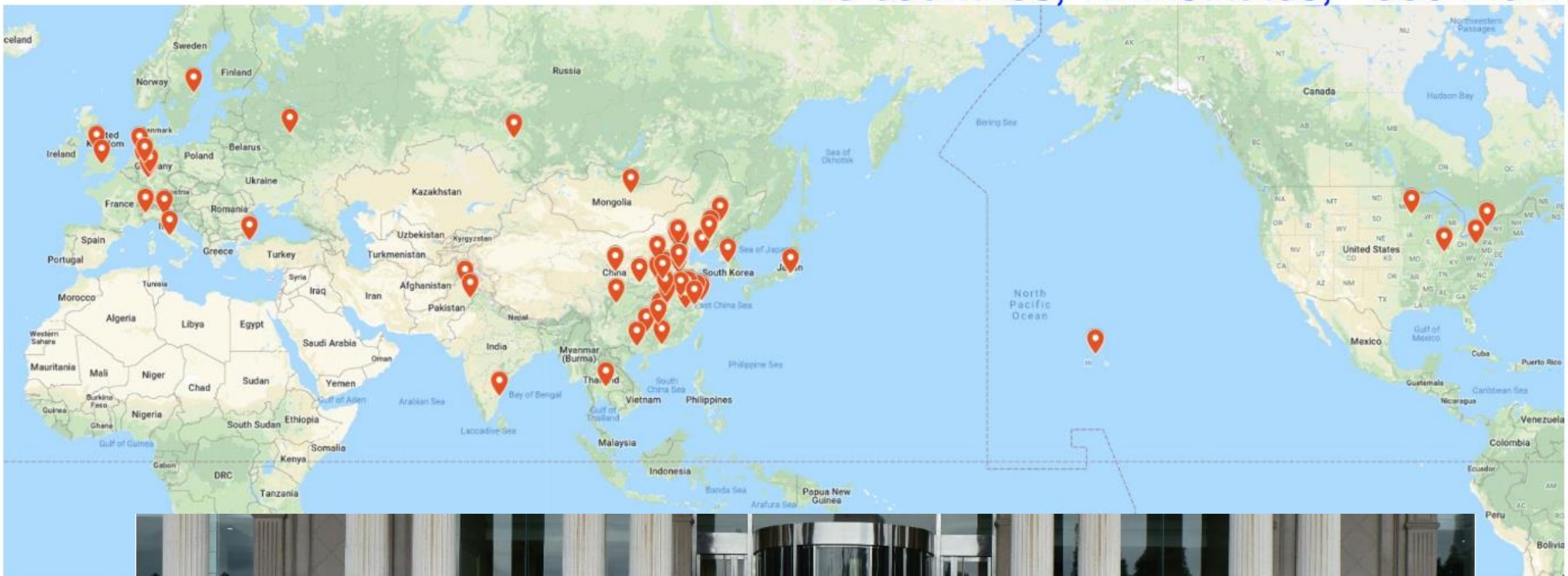
Muon ID: 9 layer RPC

Trigger: Tracks & Showers

The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

Appendix - The BESIII Collaboration

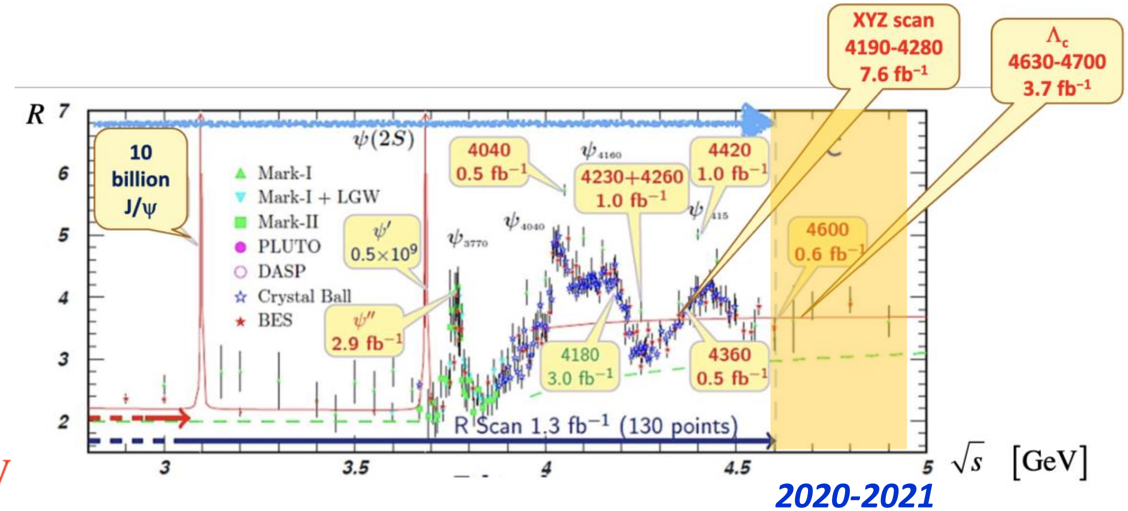
15 countries, 72 institutes, ~500 members

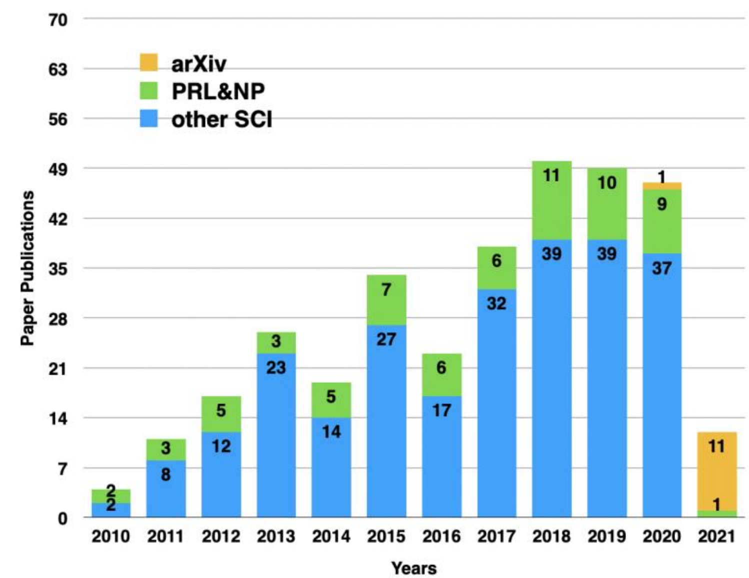


Appendix - BESIII Data Samples

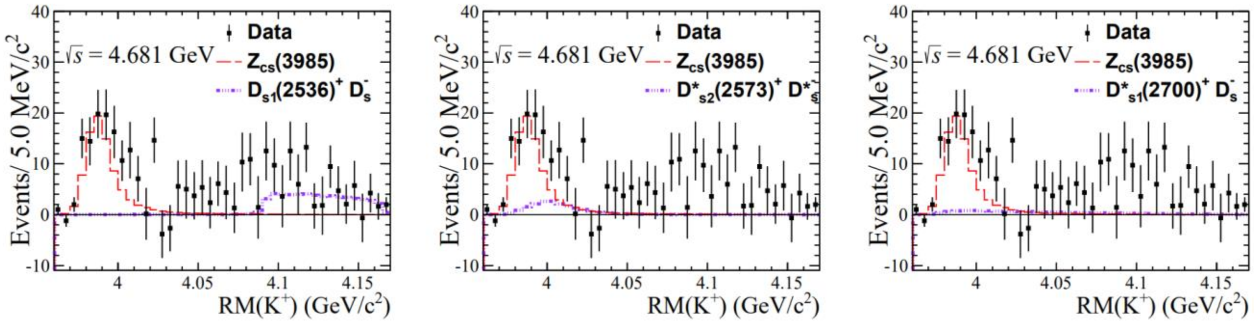
2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 pb^{-1} at $\psi(3770)$
2011: 2.9 fb^{-1} *(total)* at $\psi(3770)$
482 pb^{-1} at 4.01 GeV
2012: 0.45B *(total)* $\psi(2S)$
1.3B *(total)* J/ψ
2013: 1092 pb^{-1} at 4.23 GeV
826 pb^{-1} at 4.26 GeV
540 pb^{-1} at 4.36 GeV
10×50 pb^{-1} scan 3.81 — 4.42 GeV
2014: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

2020: 3.8 fb^{-1} scan 4.61-4.7 GeV
2021: 2 fb^{-1} scan 4.74-4.946 GeV

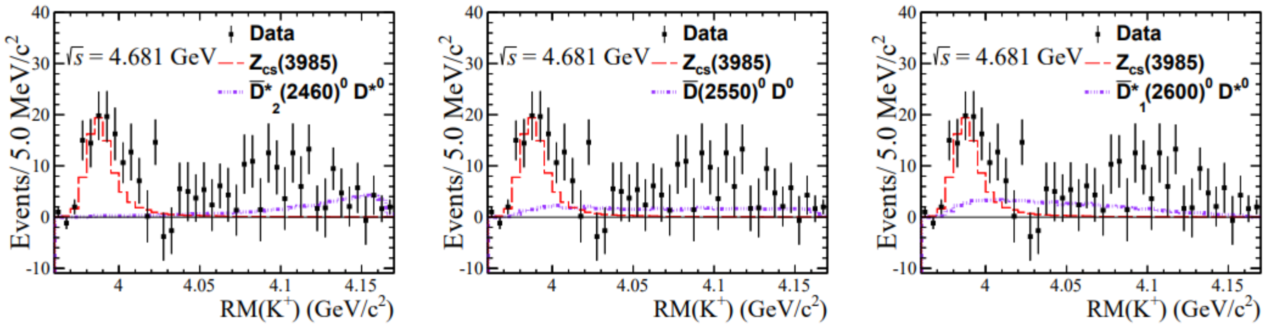




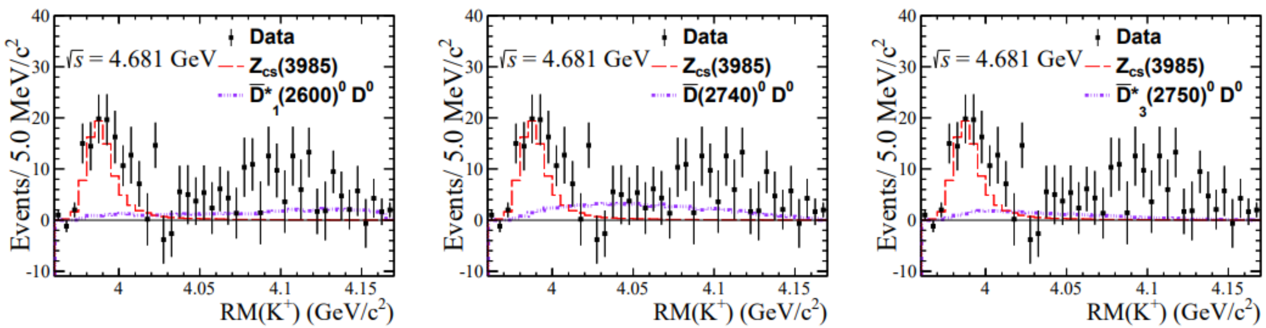
Appendix - $Z_{cs}(3985)$: All possible $D_{(s)}^{**}$ backgrounds



(a) $D_{s1}(2536)^+(\to D^{*0}K^+)D_s^-$ (b) $D^*_{s2}(2573)^+(\to D^0K^+)D_s^{*-}$ (c) $D^*_{s1}(2700)^+(\to D^{*0}K^+)D_s^-$

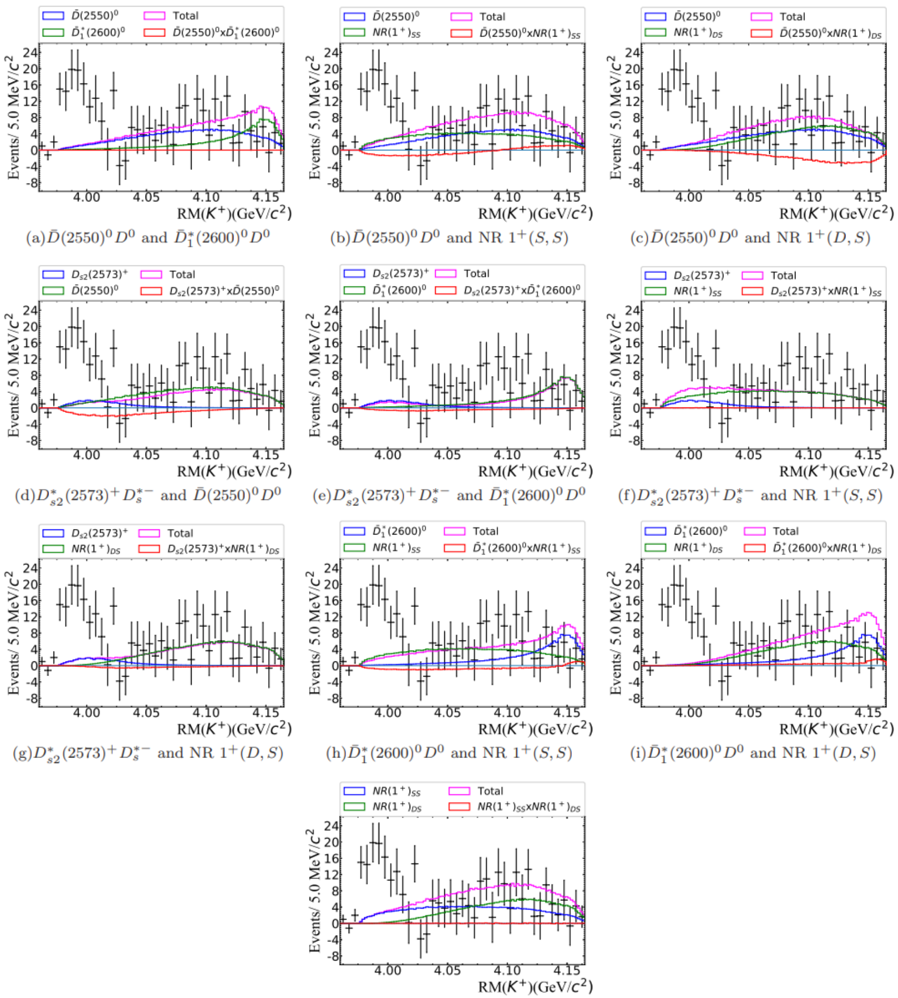


(a) $\bar{D}^*_2(2460)^0(\to D_s^-K^+)D^{*0}$ (b) $\bar{D}(2550)^0(\to D_s^{*-}K^+)D^0$ (c) $\bar{D}^*_1(2600)^0(\to D_s^-K^+)D^{*0}$

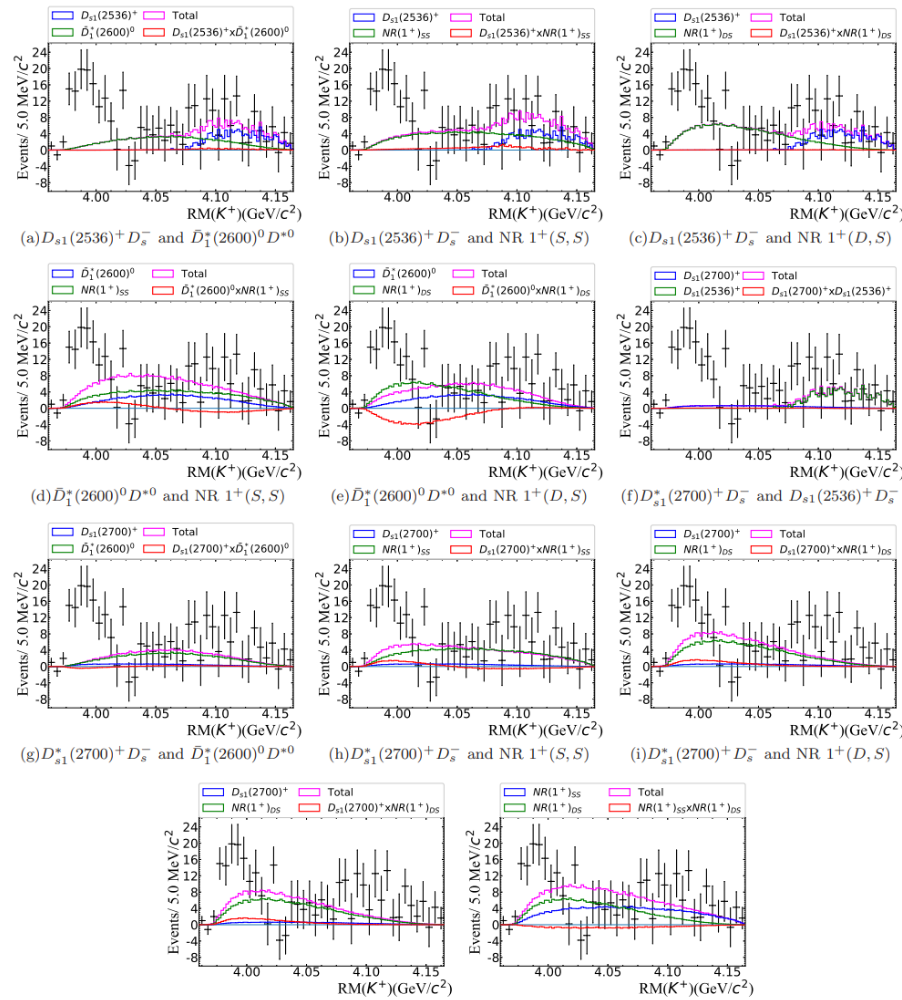


(d) $\bar{D}^*_1(2600)^0(\to D_s^{*-}K^+)D^0$ (e) $\bar{D}(2740)^0(\to D_s^{*-}K^+)D^0$ (f) $\bar{D}^*_3(2750)^0(\to D_s^{*-}K^+)D^0$

Appendix - $Z_{cs}(3985)$: Interference of $D_{(s)}^{**}$ states



(a) $\bar{D}(2550)^0 D^0$ and $\bar{D}_1^*(2600)^0 D^0$
(b) $\bar{D}(2550)^0 D^0$ and NR $1^+(S,S)$
(c) $\bar{D}(2550)^0 D^0$ and NR $1^+(D,S)$
(d) $D_{s2}^*(2573)^+ D_s^{*-}$ and $\bar{D}(2550)^0 D^0$
(e) $D_{s2}^*(2573)^+ D_s^{*-}$ and $\bar{D}_1^*(2600)^0 D^0$
(f) $D_{s2}^*(2573)^+ D_s^{*-}$ and NR $1^+(S,S)$
(g) $D_{s2}^*(2573)^+ D_s^{*-}$ and NR $1^+(D,S)$
(h) $\bar{D}_1^*(2600)^0 D^0$ and NR $1^+(S,S)$
(i) $\bar{D}_1^*(2600)^0 D^0$ and NR $1^+(D,S)$
(j) NR $1^+(S,S)$ and NR $1^+(D,S)$



(a) $D_{s1}(2536)^+ D_s^-$ and $\bar{D}_1^*(2600)^0 D^{*0}$
(b) $D_{s1}(2536)^+ D_s^-$ and NR $1^+(S,S)$
(c) $D_{s1}(2536)^+ D_s^-$ and NR $1^+(D,S)$
(d) $\bar{D}_1^*(2600)^0 D^{*0}$ and NR $1^+(S,S)$
(e) $\bar{D}_1^*(2600)^0 D^{*0}$ and NR $1^+(D,S)$
(f) $D_{s1}^*(2700)^+ D_s^-$ and $D_{s1}(2536)^+ D_s^-$
(g) $D_{s1}^*(2700)^+ D_s^-$ and $\bar{D}_1^*(2600)^0 D^{*0}$
(h) $D_{s1}^*(2700)^+ D_s^-$ and NR $1^+(S,S)$
(i) $D_{s1}^*(2700)^+ D_s^-$ and NR $1^+(D,S)$
(j) $D_{s1}^*(2700)^+ D_s^-$ and NR $1^+(D,S)$
(k) NR $1^+(S,S)$ and NR $1^+(D,S)$

✓ For $K^+ D_s^{*-} D^0$ final states

✓ For $K^+ D_s^- D^{*0}$ final states