New observations of Charmonium decays at BESIII

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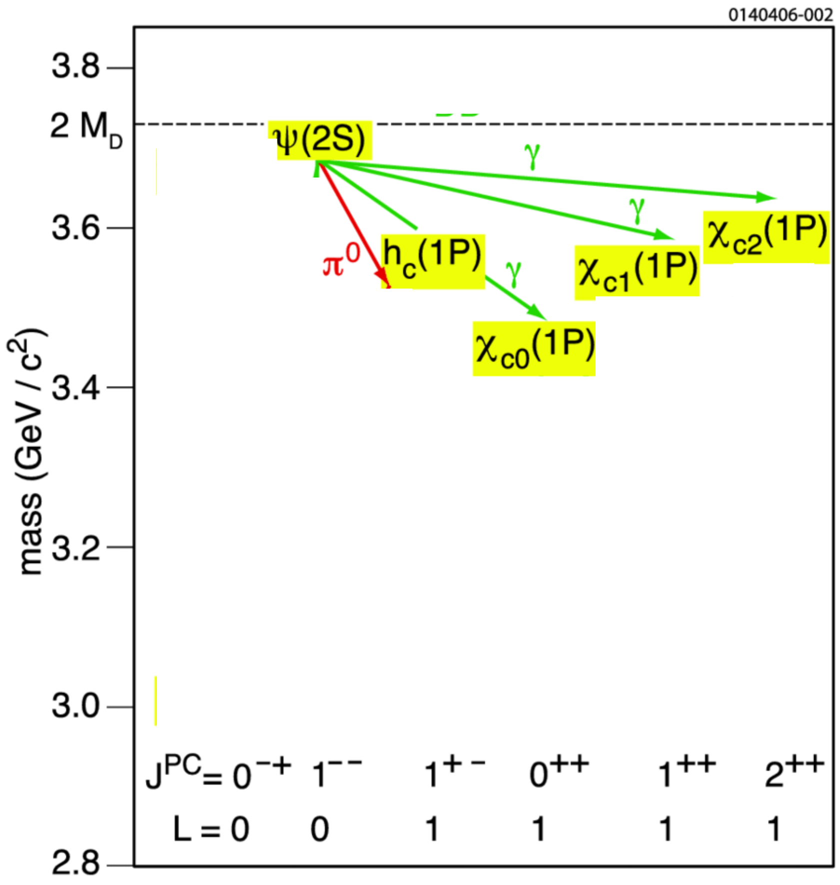
Outline

- Introduction
- Recent observations about Charmonium decays:
  - Ψ(3686) decays
  - h_c decays
  - χ_{cJ} decays
- Summay and prospects

All are first observations!

BESIII is unique!

- $\Psi(3686)$ or $\Psi(2S)$: produced directly in electron-positron collision; In year 2009 and 2012, $(448.1\pm2.9)\times10^6$ events were collected **[1]**, largest in the world!
- h_c decays: $Br(\Psi(3686) \to \pi^0 h_c) \backsim 9\times10^{-4}$ **[2]**, π^0 could be fully reconstructed. Complicated hadronic decays could be studied!
- χ_{cJ} decays: $Br(\Psi(3686) \to \gamma\chi_{cJ}) \backsim 10\%$, $E\gamma > 100$ MeV, which is detectable at BESIII**[2]**, very low background!



(From Eichten et cl)

[1] *Chin. Phys. C* 42 (2018)
[2] PDG 2020

Phys. Rev. D 99, 112010 (2019)

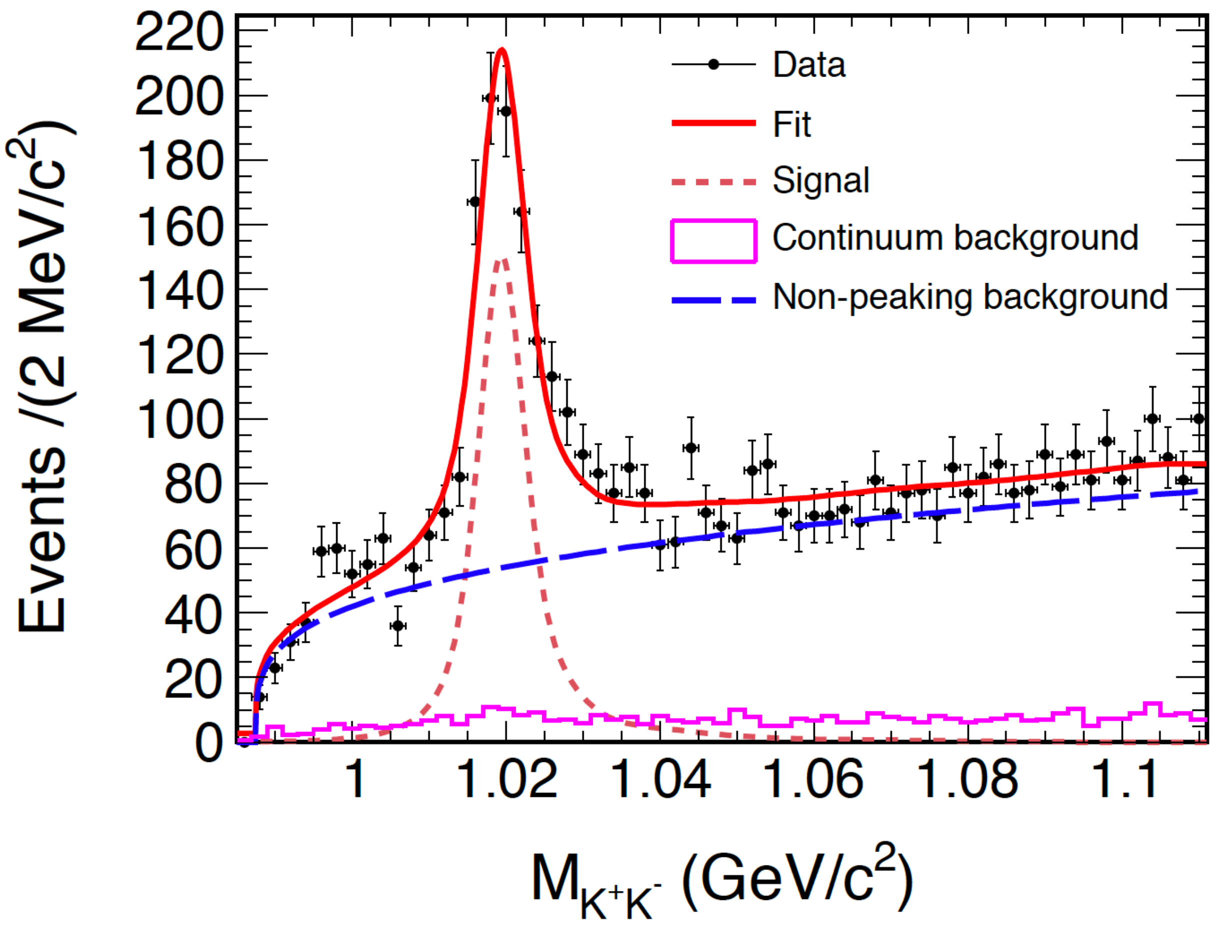
Observation of ψ(3686)→$\mathbf{p}\bar{p}\phi$

❖Search for the intermediate structure among the three bodies, such as the X($p\bar{p}$)

❖Test the 12% rule:

$$Q = \frac{B_{\psi(3686)\to h}}{B_{J/\psi\to h}} = \frac{B_{\psi(3686)\to l^+l^-}}{B_{J/\psi\to l^+l^-}} = (12.4 \pm 0.4)\%.$$

(By PQCD)



Phys. Rev. D 99, 112010 (2019)

Observation of $\psi(3686)\to p\bar{p}\phi$

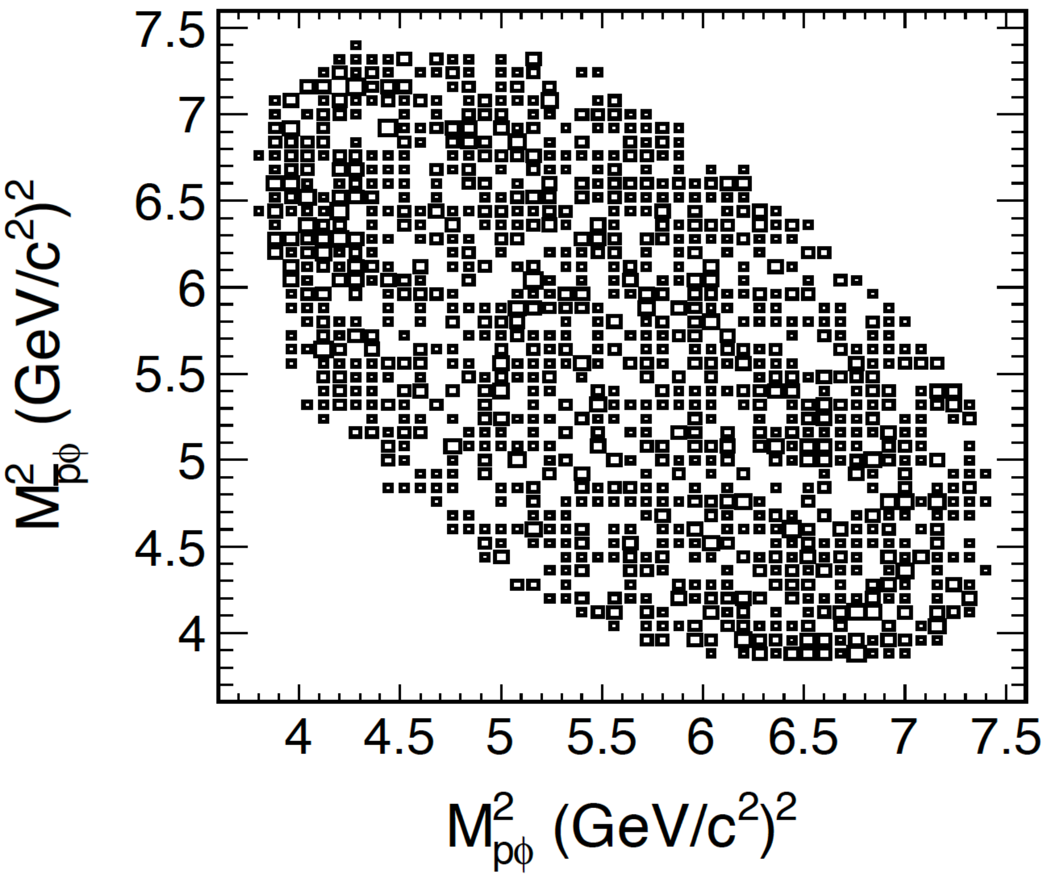
First observation!

The brancing ratio is measured to be:

$(6.06\pm0.38\pm0.48)\times10^{-6}$,

Q= (11.6±0.7 ±1.2)%

No significant intermediate structures!



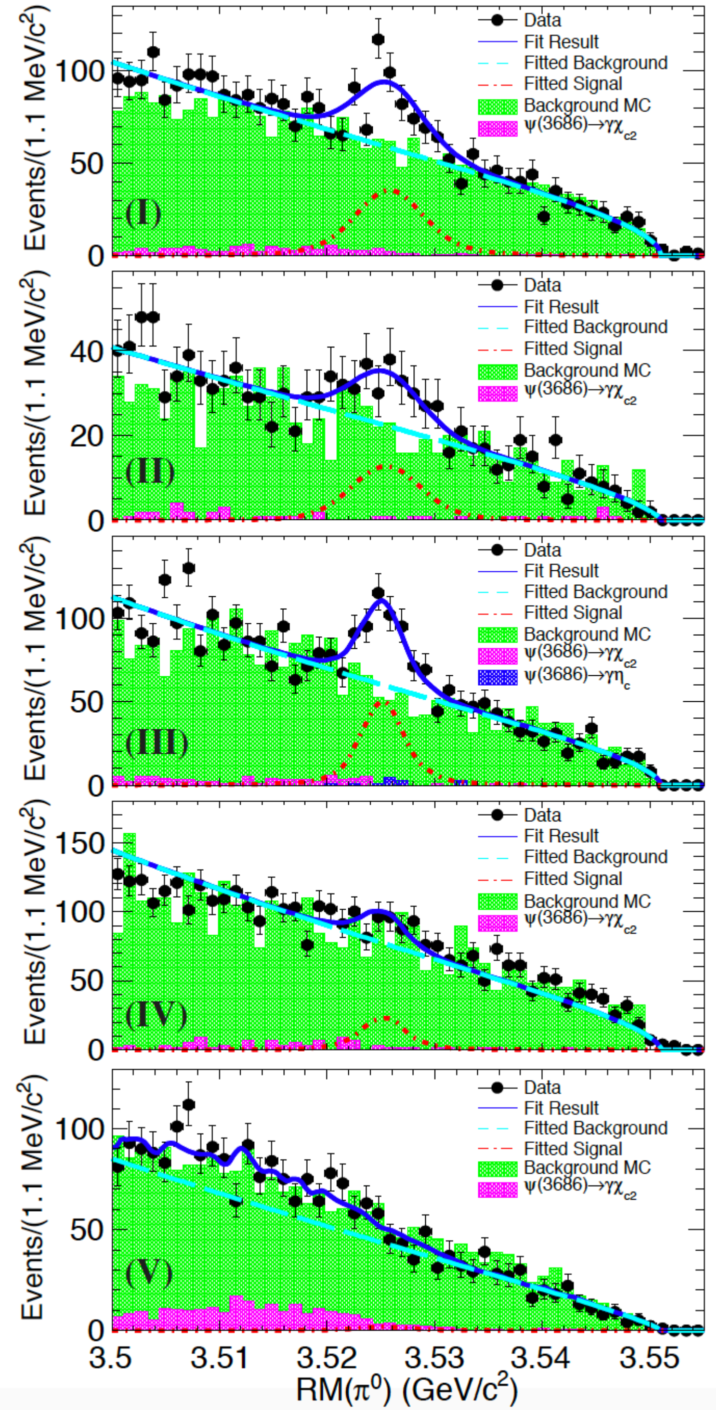
Phys. Rev. D 99, 072008 (2019)

h_c new hadronic decays

- Not much observed hadronic decays of h_c;
- Test the QCD, and the input for other measurement.

First observation!

Mode		$\epsilon(\%)$	N_{hc}	$\mathcal{B}_{\psi(3686)} \times \mathcal{B}_{h_c}(10^{-6})$	$\mathcal{B}_{h_c}(10^{-3})$	S.S.	$\mathcal{B}_{h_c}^{\text{PDG}}(10^{-3})$
I	$h_c \to p\bar{p}\pi^+\pi^-$	20.9	230 ± 25	$2.49 \pm 0.27 \pm 0.28$	$2.89 \pm 0.32 \pm 0.55$	7.4σ	–
II	$h_c \to \pi^+\pi^-\pi^0$	16.8	101 ± 25	$1.38 \pm 0.35 \pm 0.17$	$1.60 \pm 0.40 \pm 0.32$	4.6σ	< 2.2
III	$h_c \to 2(\pi^+\pi^-)\pi^0$	9.1	254 ± 32	$6.40 \pm 0.81 \pm 0.87$	$7.44 \pm 0.94 \pm 1.52$	9.1σ	22^{+8}_{-7}
IV	$h_c \to 3(\pi^+\pi^-)\pi^0$	4.2	73 ± 34 < 136	$4.00 \pm 1.87 \pm 0.70$ < 7.5	$4.65 \pm 2.17 \pm 1.08$ < 8.7	2.1σ –	< 29
V	$h_c \to K^+K^-\pi^+\pi^-$	18.1	<40	< 0.5	< 0.6	–	–

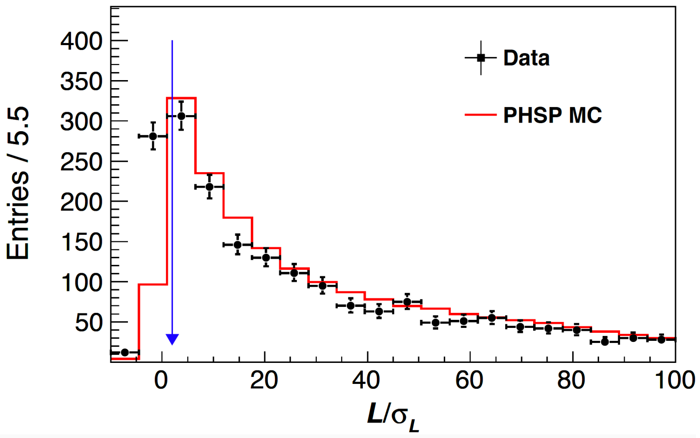


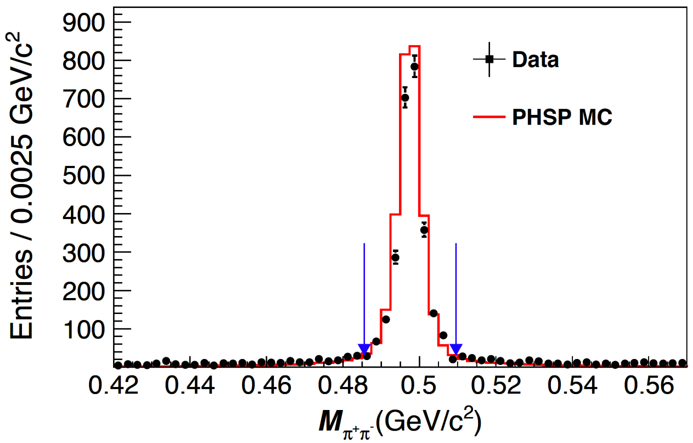
Phys. Rev. D 99, 052008 (2019)

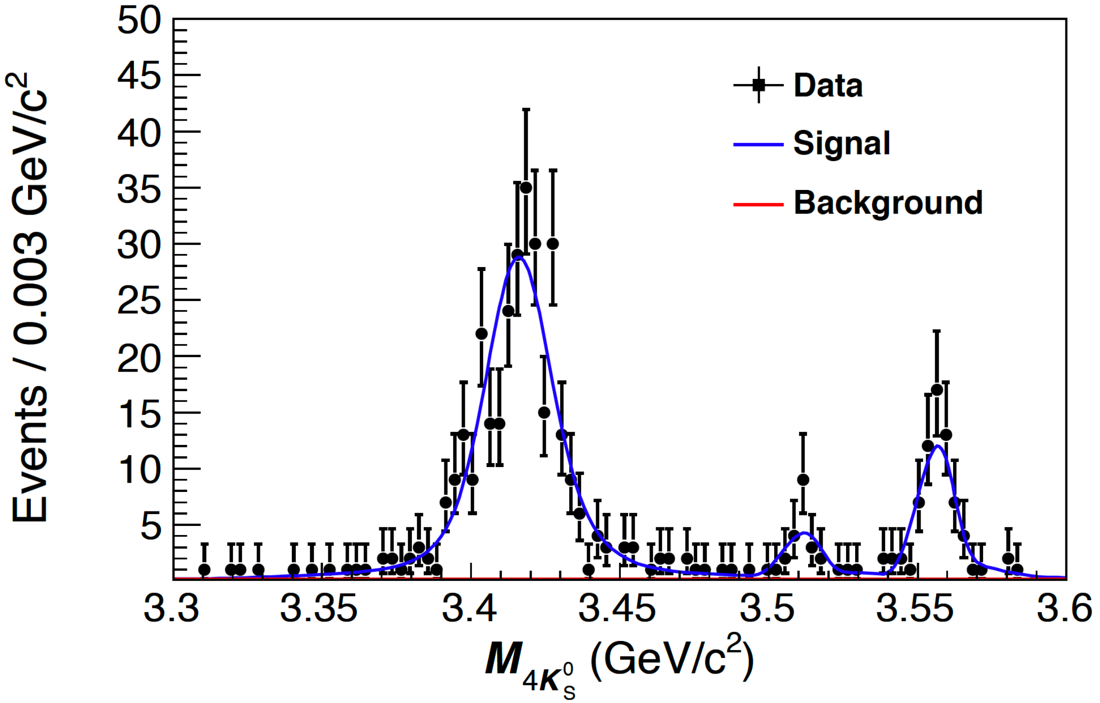
Observation of $\chi_{cJ} \to 4K_S^0$

First observation!

The selection of K_S^0 relies on decay length and the invariant mass of the two pions:







$Br(\chi_{c0} \to 4K_S^0) = (5.76 \pm 0.34 \pm 0.38) \times 10^{-4}$

$Br(\chi_{c1} \to 4K_S^0) = (0.35 \pm 0.09 \pm 0.03) \times 10^{-4}$

$Br(\chi_{c2} \to 4K_S^0) = (1.14 \pm 0.15 \pm 0.08) \times 10^{-4}$

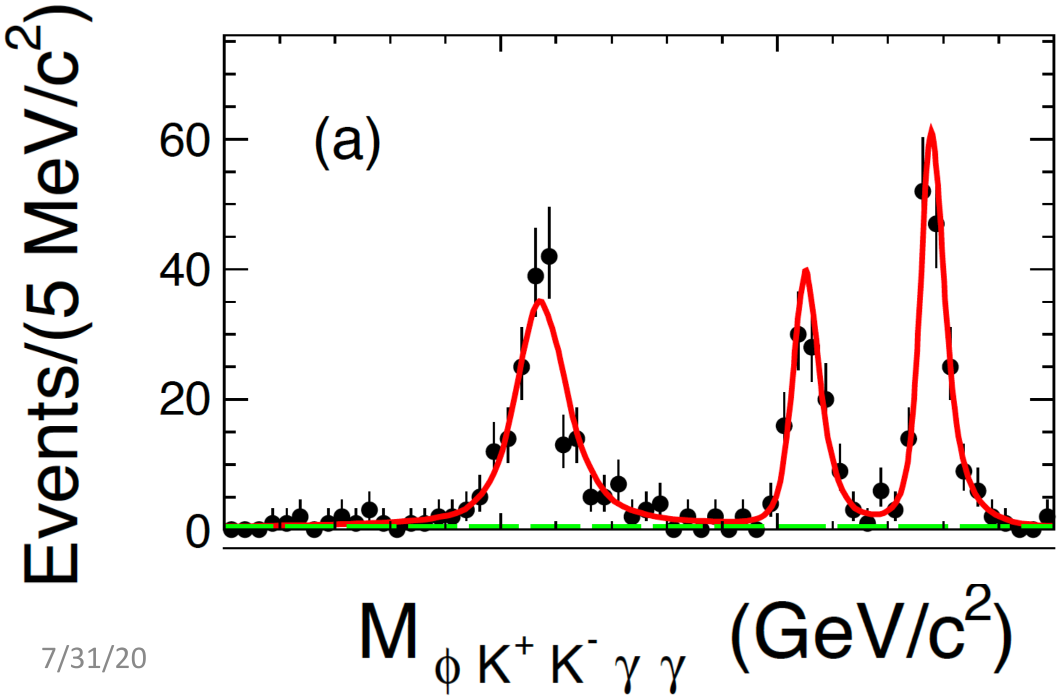
Phys. Rev. D 101, 012012 (2020)

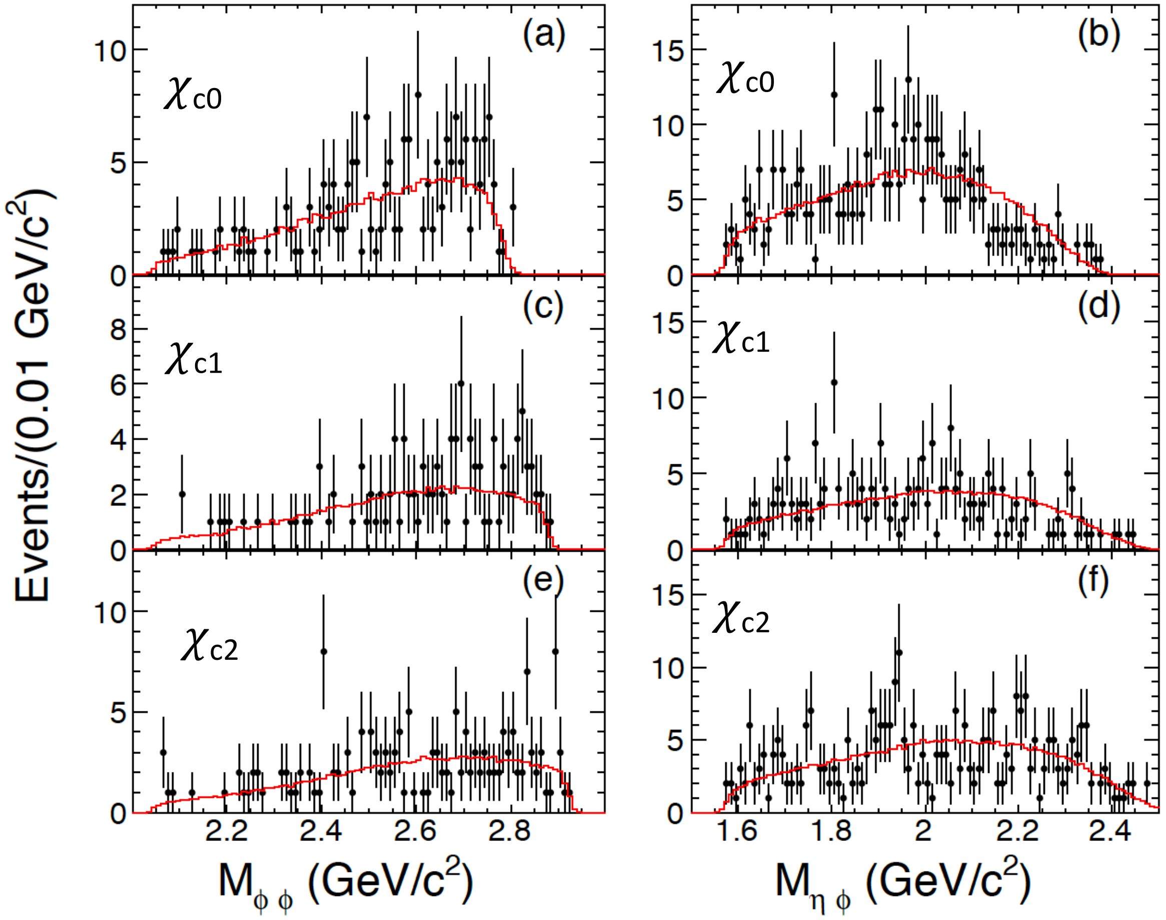
First observation!

Observation of $\chi_{cJ} \to \phi\phi\eta$

BRs:

Mode	$\mathcal{B}(\times 10^{-4})$
$\chi_{c0} \to \phi\phi\eta$	$8.41 \pm 0.74 \pm 0.62$
$\chi_{c1} \to \phi\phi\eta$	$2.96 \pm 0.43 \pm 0.22$
$\chi_{c2} \to \phi\phi\eta$	$5.33 \pm 0.52 \pm 0.39$



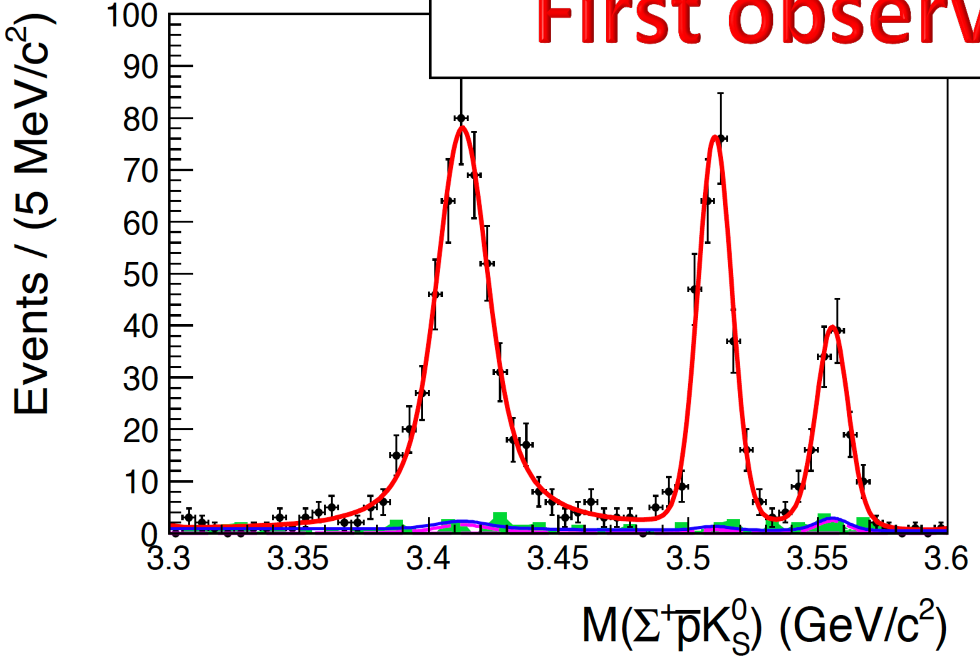


No obvious structure is observed!

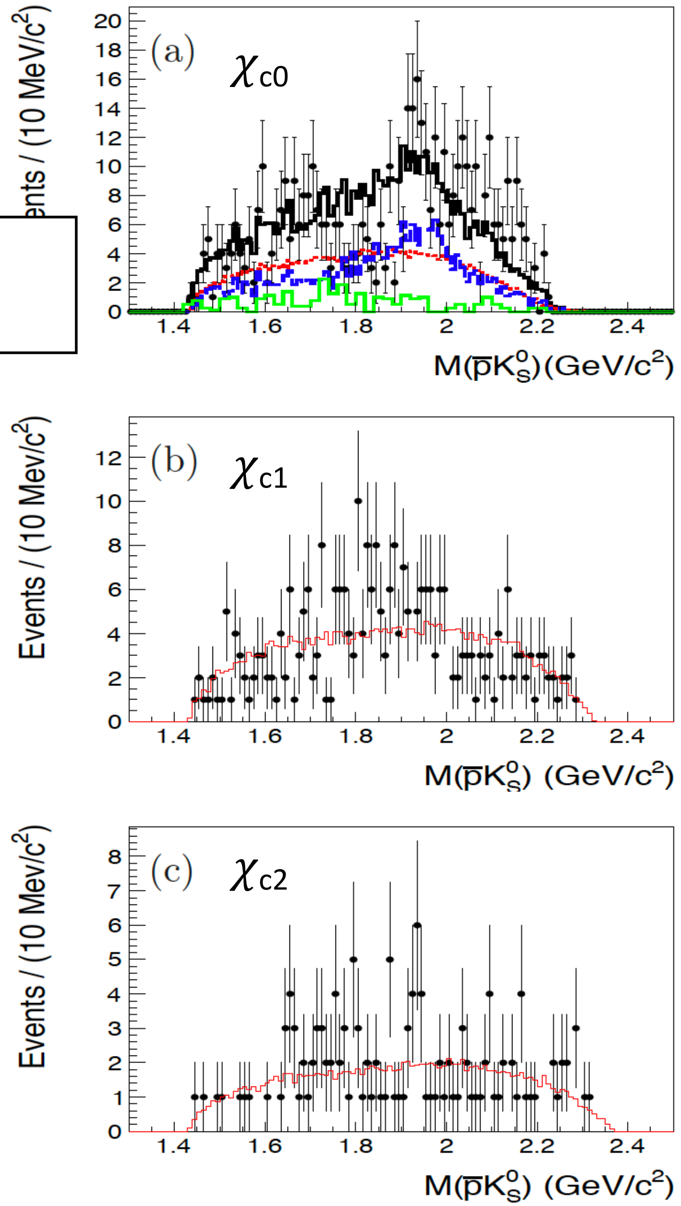
Phys. Rev. D 100, 092006 (2019)

Observation of $\chi_{cJ} \to \Sigma^+ \bar{p} K_S^0$

First observation!



Mode	$N_{obs}^{\chi_{cJ}}$	$\epsilon(\%)$	$\mathcal{B}(\chi_{cJ} \to \Sigma^+ \bar{p} K_S^0)$
$\chi_{c0} \to \Sigma^+ \bar{p} K_S^0$	493 ± 26	9.05 ± 0.05	$(3.52 \pm 0.19 \pm 0.21) \times 10^{-4}$
$\chi_{c1} \to \Sigma^+ \bar{p} K_S^0$	258 ± 17	10.96 ± 0.05	$(1.53 \pm 0.10 \pm 0.08) \times 10^{-4}$
$\chi_{c2} \to \Sigma^+ \bar{p} K_S^0$	129 ± 13	10.40 ± 0.05	$(8.25 \pm 0.83 \pm 0.49) \times 10^{-5}$



$\Sigma^-(1940)$ 3.2σ

Red: MC
Green: side-band
Blue: $\chi_{cJ} \to \Sigma^+ \Sigma^-$

Search for excited baryons

Phys. Rev. D 100 , 052010 (2019)

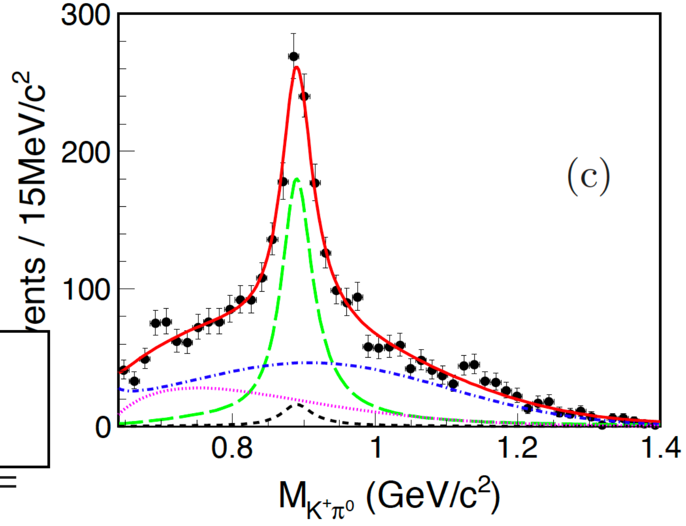
Observation of $\psi(3686)\ /\chi_{cJ} \rightarrow \bar{p}K^{*+}\Lambda$

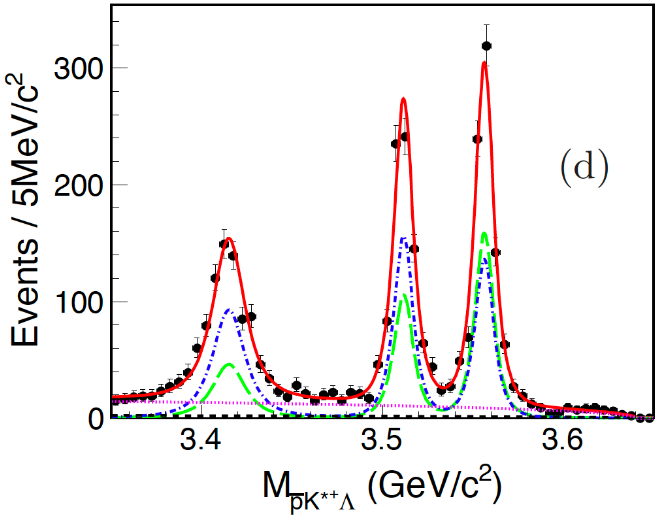
Motivation:

1. Measure the braching fractions;
2. Search for possible intermediate states

First observation!

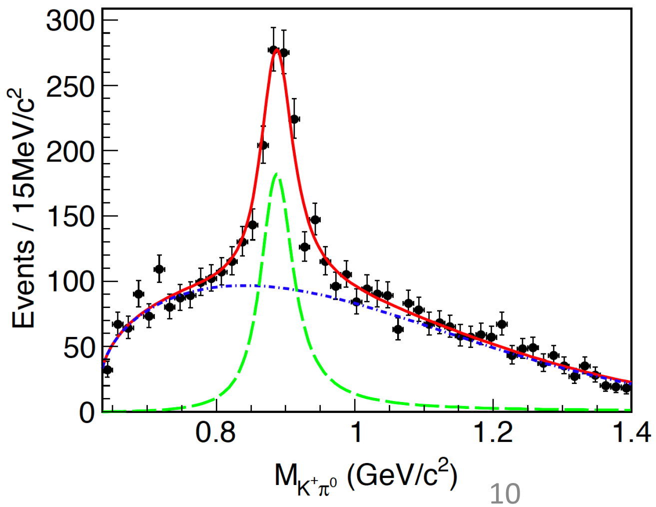
Decay channel	Branching fraction
$\psi(3686) \to \gamma\chi_{c0} \to \gamma\bar{p}K^{*+}\Lambda$	$(4.7 \pm 0.7 \pm 0.5) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c1} \to \gamma\bar{p}K^{*+}\Lambda$	$(4.8 \pm 0.5 \pm 0.4) \times 10^{-5}$
$\psi(3686) \to \gamma\chi_{c2} \to \gamma\bar{p}K^{*+}\Lambda$	$(7.8 \pm 0.9 \pm 0.6) \times 10^{-5}$
$\chi_{c0} \to \bar{p}K^{*+}\Lambda$	$(4.8 \pm 0.7 \pm 0.5) \times 10^{-4}$
$\chi_{c1} \to \bar{p}K^{*+}\Lambda$	$(5.0 \pm 0.5 \pm 0.4) \times 10^{-4}$
$\chi_{c2} \to \bar{p}K^{*+}\Lambda$	$(8.2 \pm 0.9 \pm 0.7) \times 10^{-4}$
$\psi(3686) \to \bar{p}K^{*+}\Lambda$	$(6.3 \pm 0.5 \pm 0.5) \times 10^{-5}$





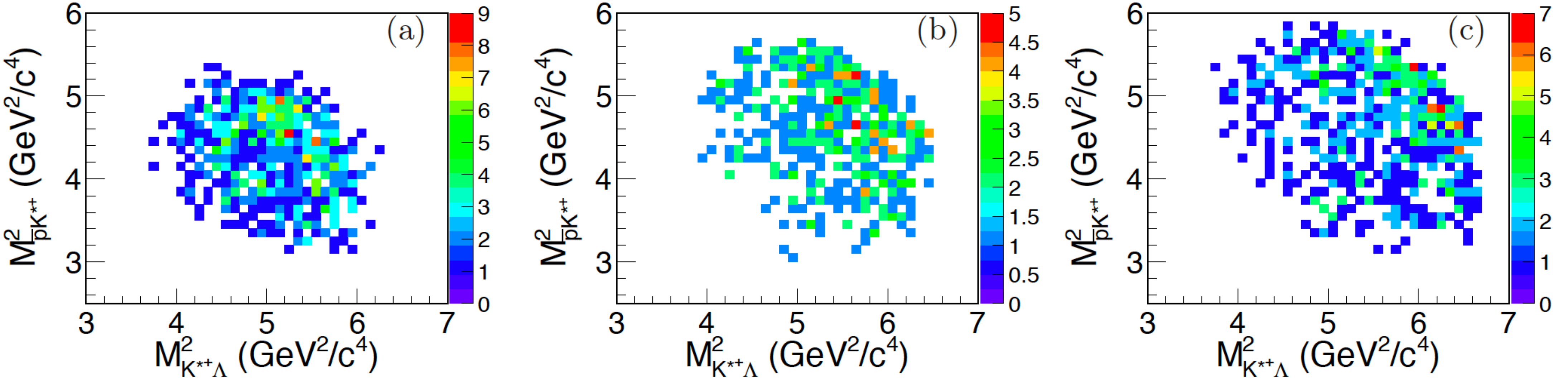
2D fit for χ_{cJ}: green is signal; black is K*+non- χ_{cJ}; blue is non-K*+ χ_{cJ}; pink is non-K*+non- χ_{cJ}. (up plots)

1D fit for ψ(3686) (bottom plot)



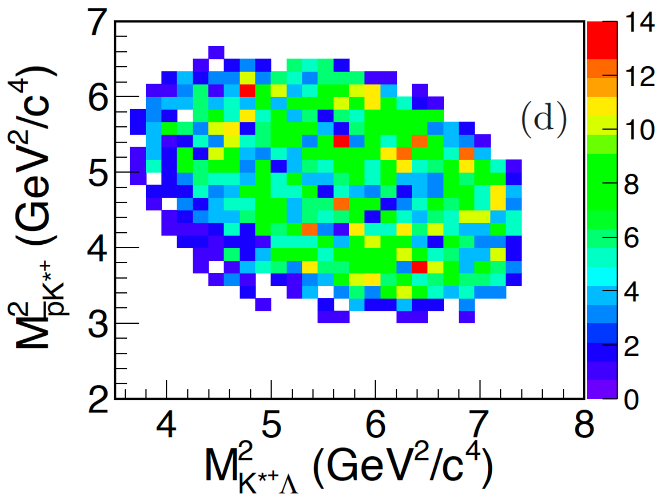
Phys. Rev. D 100 , 052010 (2019)

Observation of ψ(3686) /$\chi_{cJ} \to \bar{p}K^{*+}\Lambda$



No significant intermediate states are observed!
(a) $\chi_{c0.}$ (b) $\chi_{c1.}$ (c) $\chi_{c2.}$ (d) ψ(3686)

The Dalitz plot from ψ(3686) seems to be different from that for χ_{cJ} !



Summary and prospects

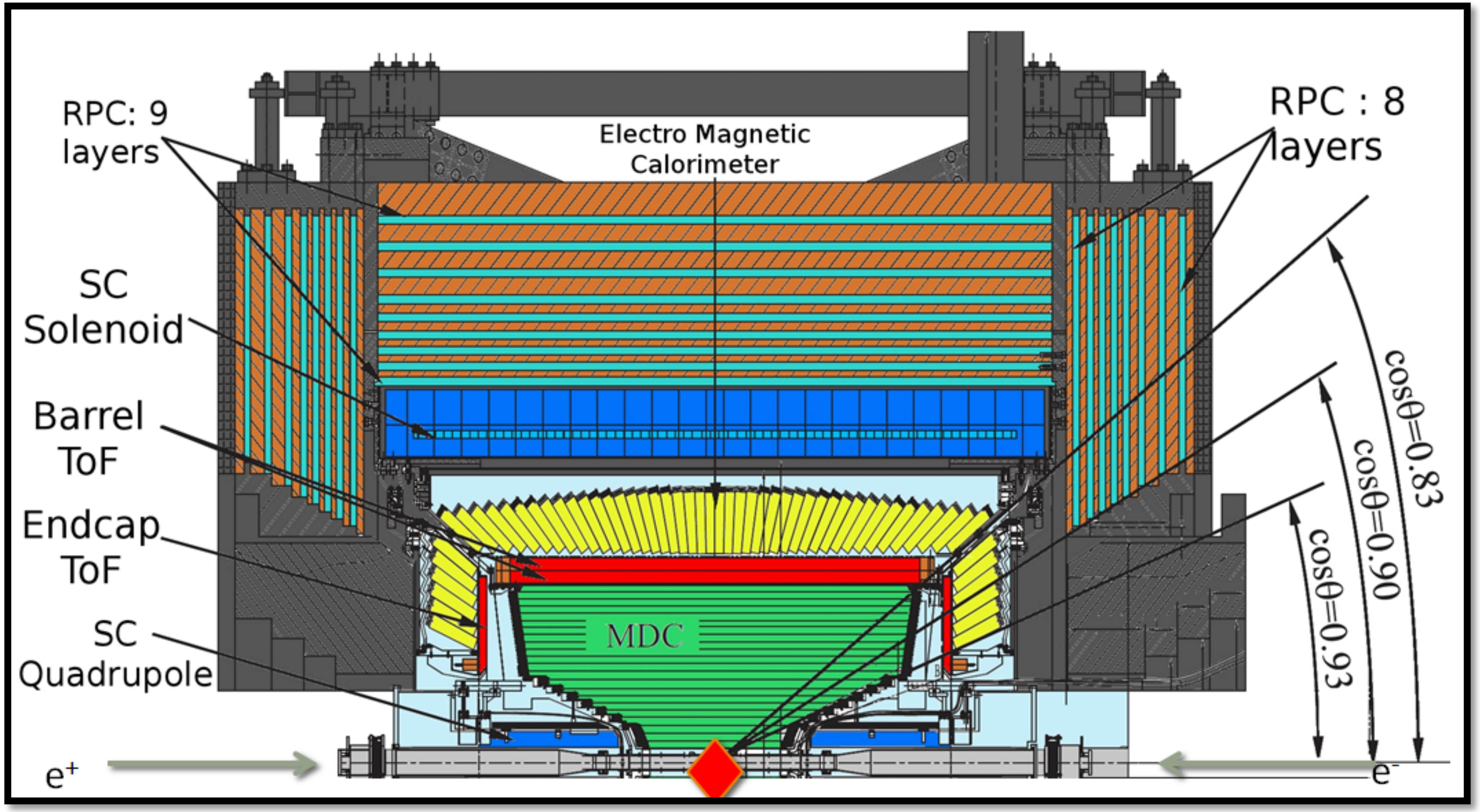
- Based on 450 million of $\psi(3686)$ events, many decay modes of $\psi(3686)$, h_c and χ_{cJ} are observed for the first time, and these results are crucial inputs for understanding the QCD in the low energy regime;
- In the future, BESIII plans to enlarge the $\psi(3686)$ sample by a factor of 5 or more.

Upgraded Beijing Electron Positron Collider (BEPCII)

2004: started BEPCII/BESIII construction
2008: test run
2009 - now: BESIII physics run

Beam energy:
1-2.35 GeV
(will run up to 2.45 GeV next year)
Design luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
Bunch length:1.5 cm
Total current: 0.91 A
Linac: ~200 m
Circular:~240 m
Double rings with tiny crossing angle

BESIII detector



Charged-particle momentum resolution@1GeV: 0.5%

Photon energy resolution@1 GeV: 2.5% (5%) for barrel (endcap); position resolution 6mm

dE/dx resolution: 6% for electrons from Bhabha process

Time resolution of TOF: 68 ps (60 ps) for barrel (endcap)

SC magnetic: 1 T

Trigger and DAQ: 4 kHz, with event size 12 Kbytes

>500 Members