arXiv:1308.2760

Observation of a charged charmoniumlike structure Zc(4025) in $e^+e^- \to D^{*+}\overline{D}^{*0}\pi^-$ at BESIII

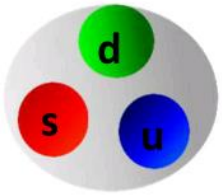
Xiao-Rui Lu (吕晓睿)

University of Chinese Academy of Sciences (UCAS), Beijing

（中国科学院大学，北京）

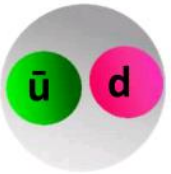
(representing the BESIII collaboration)

QCD allows multiquark hadrons



Baryons are red-blue-green triplets

Mesons are color-anticolor pairs



ordinary matter

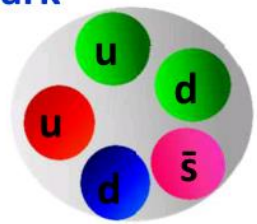
Λ=usd

π=ūd

Other possible combinations of quarks and gluons :

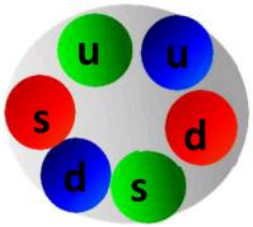
Pentaquark

S= +1
Baryon



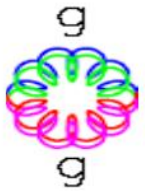
H di-Baryon

Tightly bound
6 quark state



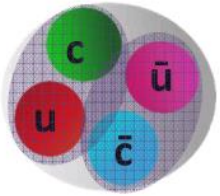
Glueball

Color-singlet multi-gluon bound state



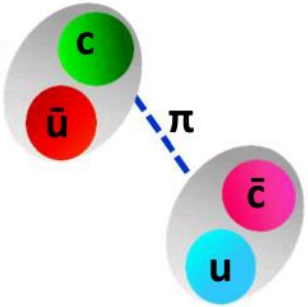
Tetraquark

Tightly bound diquark & anti-diquark

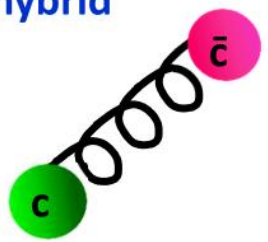


Molecule

loosely bound meson-antimeson "molecule"



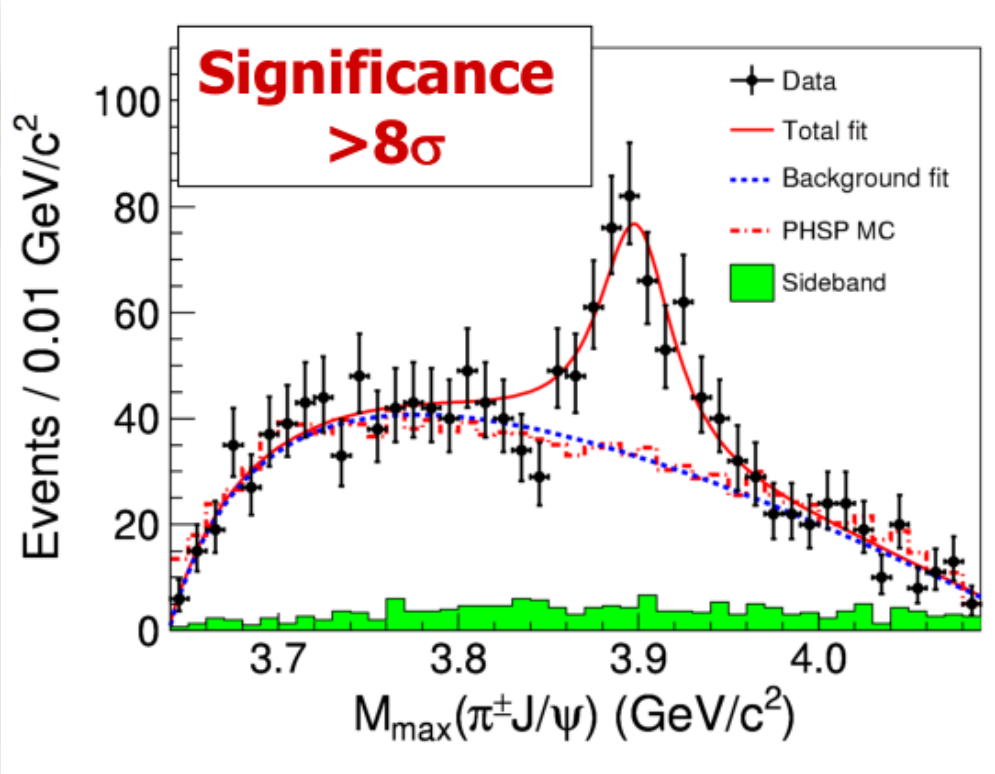
qq̄ -gluon hybrid mesons



However, none of them are established and they are exotica!!!

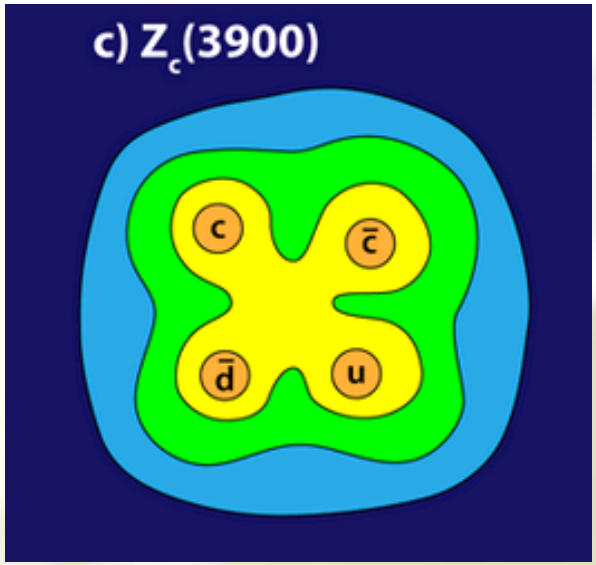
$Zc^+(3900)$ discovered at BESIII

Phys. Rev. Lett(2013) 252001



Mass = (3899.0±3.6±4.9) MeV
Width = (46±10±20) MeV

confirmed by BELLE and with CLEO-c data



from APS/Alan Stonebraker

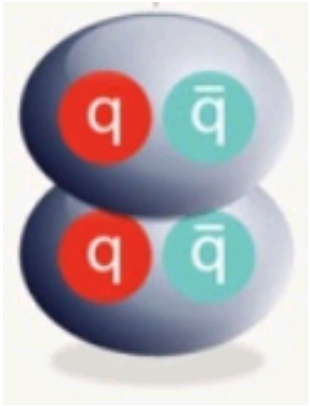
- Couples to $c\bar{c}$
- Has electric charge **1**

➔ consists of at least four quarks of $c\bar{c}u\bar{d}$

Nature of the exotic $Zc^+(3900)$

- Its mass lies close to the threshold of m(D)+m(D*)

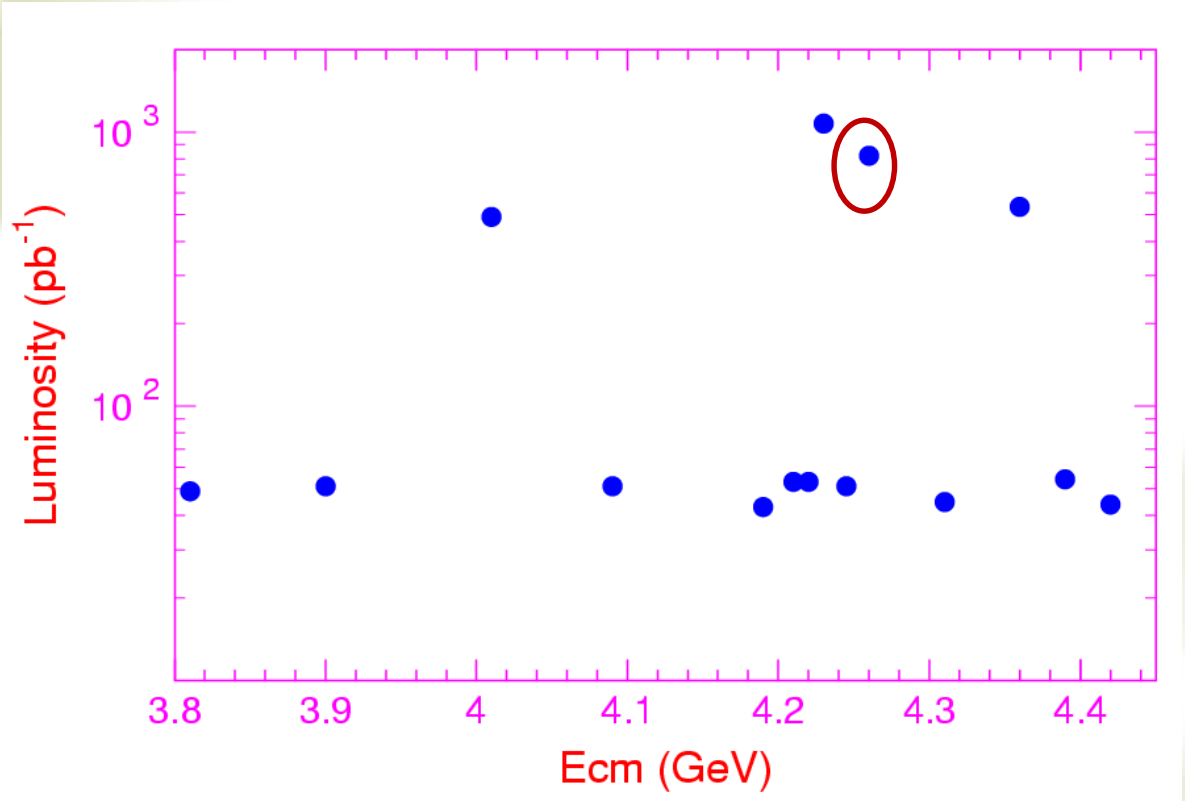
meson molecule? ***tetraquark?***



and other scenarios ...

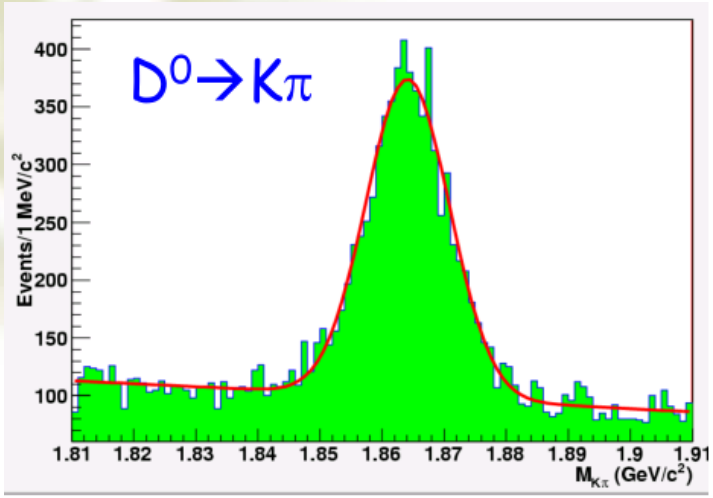
- Is there an excited partner Z'c?
- It very probably decays to $(D^*D^*)^{\pm}$ final states, if exists as a meson *molecule*

Do search in $e^+e^- \to \pi^\pm(D^*\bar{D}^*)^\mp$



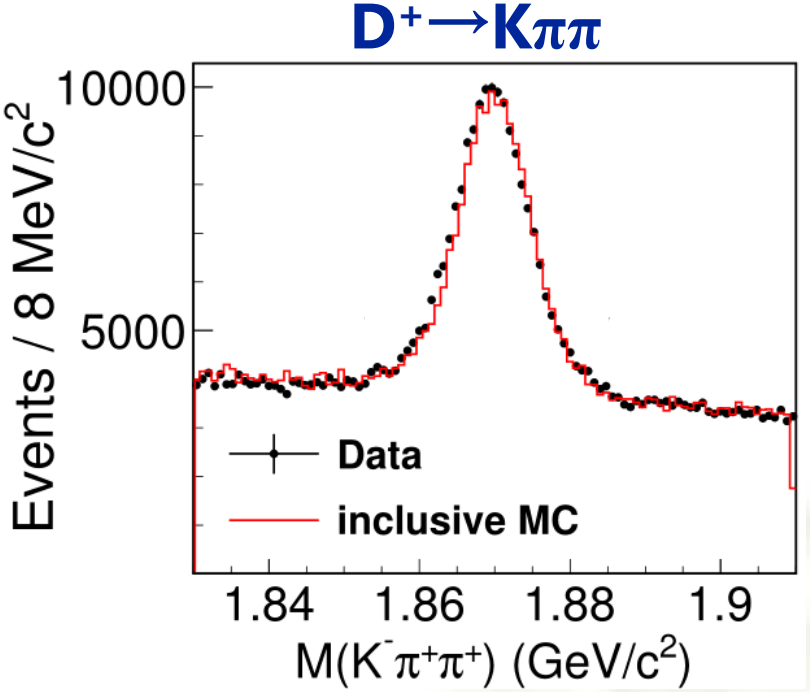
- ✓ We analyze 827/pb data @4.26GeV taken at BESIII
- ✓ Energy point is optimized
  - clean backgrounds
  - larger phase space

Data quality and MC simulation



$\Delta M_D = 0.5 \pm 0.2$ MeV

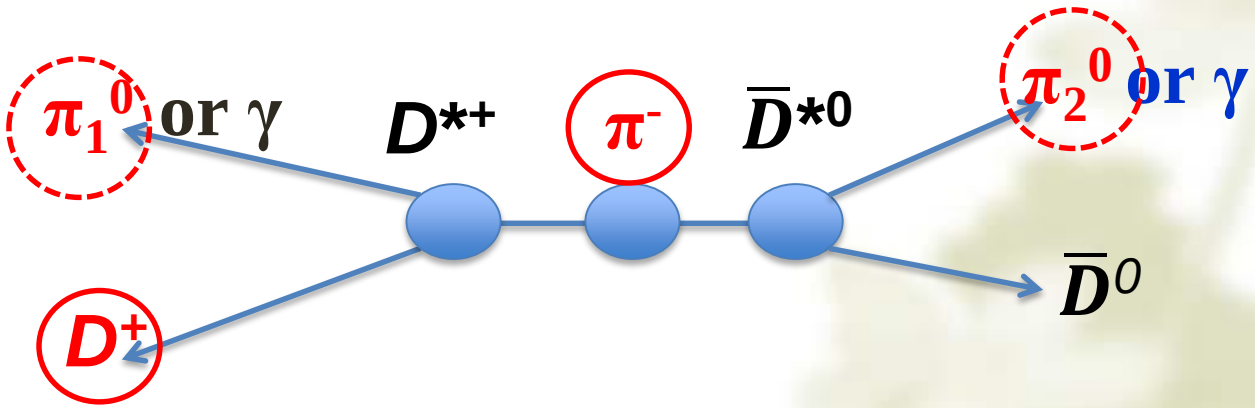
$\sigma M_D = 6.0 \pm 0.1$ MeV



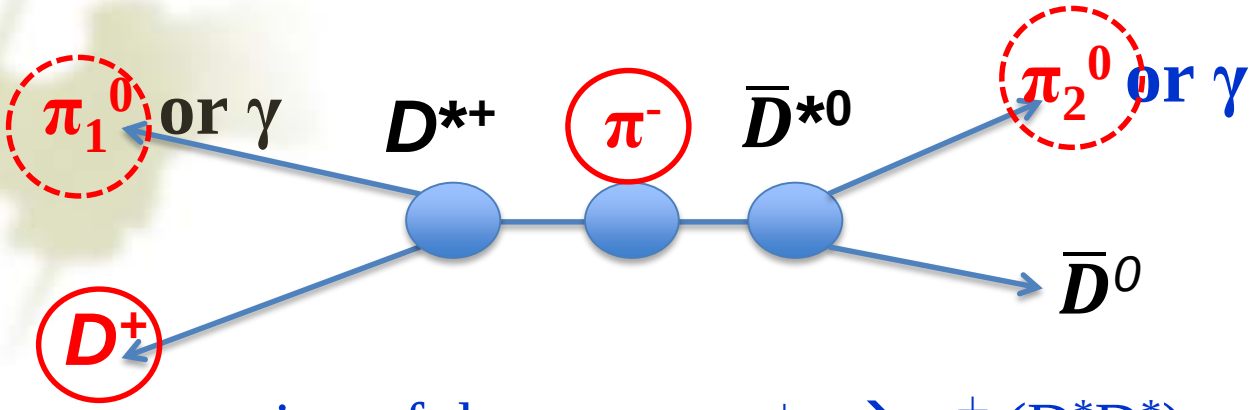
- Detector in good shape
  - Low beam background, low noise, all sub-detectors excellent!
- Improved efficiency of the BESIII software
- Excellent agreement between data and MC simulation
  - well controlled systematic uncertainty

How to identify $e^+e^- \to \pi^\pm(D^*\overline{D}^*)^\mp$ events

- partial reconstruction of the process $e^+e^- \to D^{*+}\overline{D}^{*0}\pi^-(c.c.)$ at $\sqrt{s} = 4.26GeV$
- detect a D+ and a bachelor π^- (*c.c. is implied*); to improve the significance, a π^0 is required, which decays either from D^{*+} or from $\overline{D}^{*0}$.



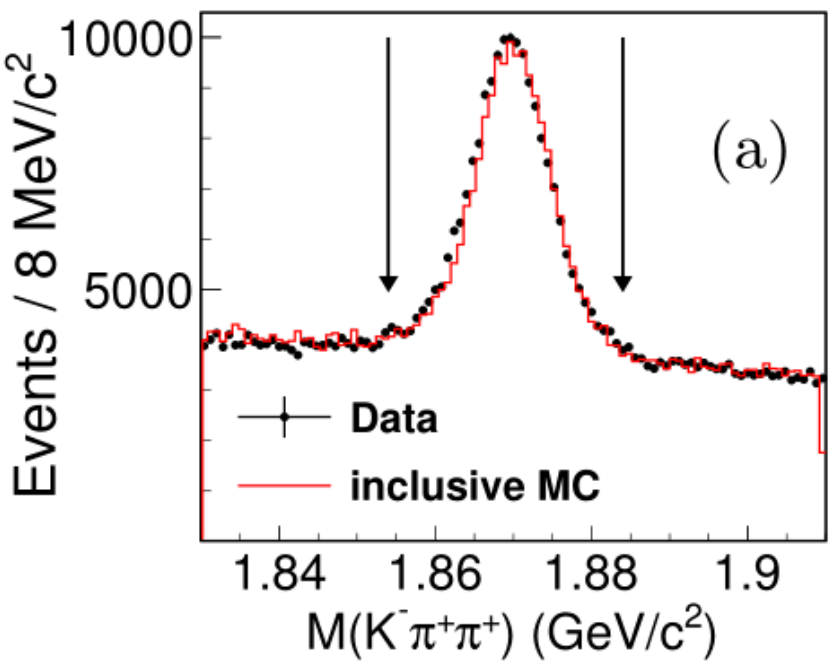
Analysis strategy (details)

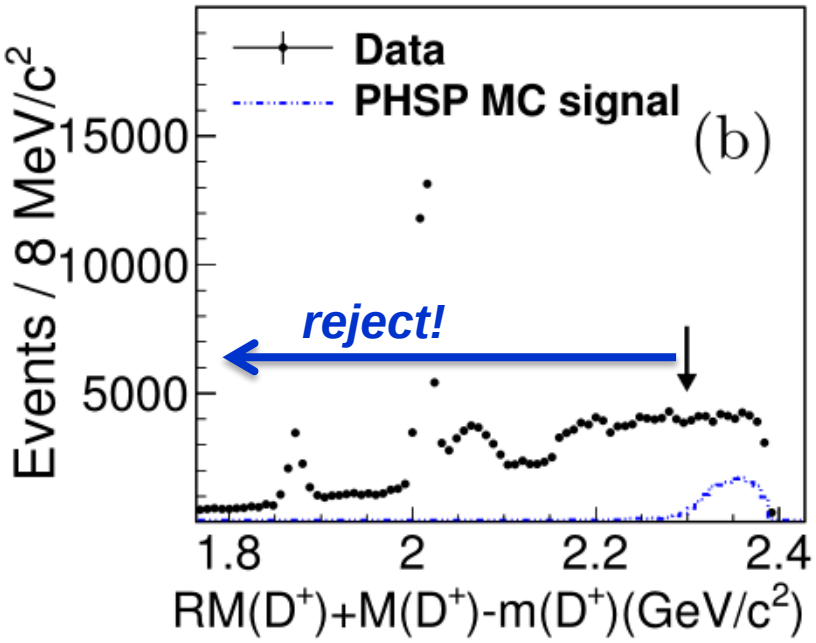


- Partial reconstruction of the process $e^+e^- \rightarrow \pi^{\pm} (D^*D^*)$
  - tag a D^+ meson in an event
  - find an additional charged π^-
  - reject backgrounds from $e^+e^- \rightarrow D^{(*)}D^{(*)}$
  - use signature in the recoil mass spectrum of $D^+\pi^-$ to identify the process of $e^+e^- \rightarrow \pi^- D^{*+}\underline{D}^{*0}$
  - to improve the significance, at least one of the π_1^0/π_2^0 is detected
  - study the mass spectrum of recoil π^-

all the plots in the talk are combinations of the c.c. modes

Tag a D^+ and reject two-body processes



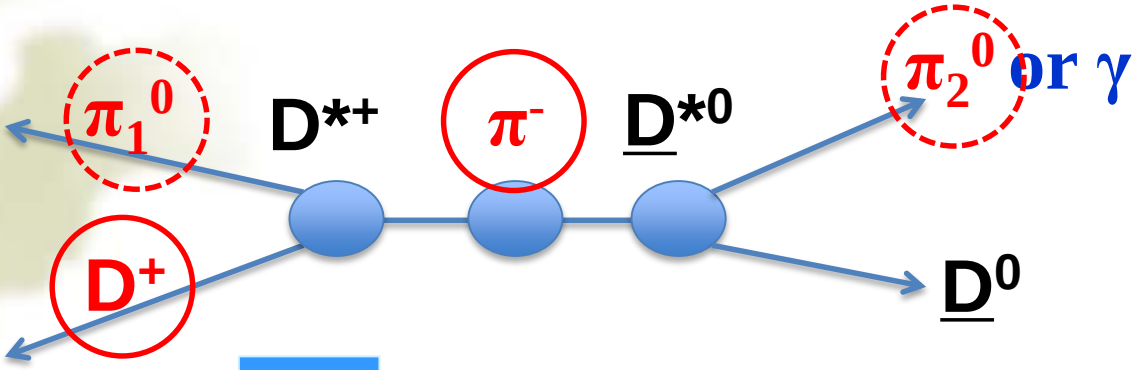


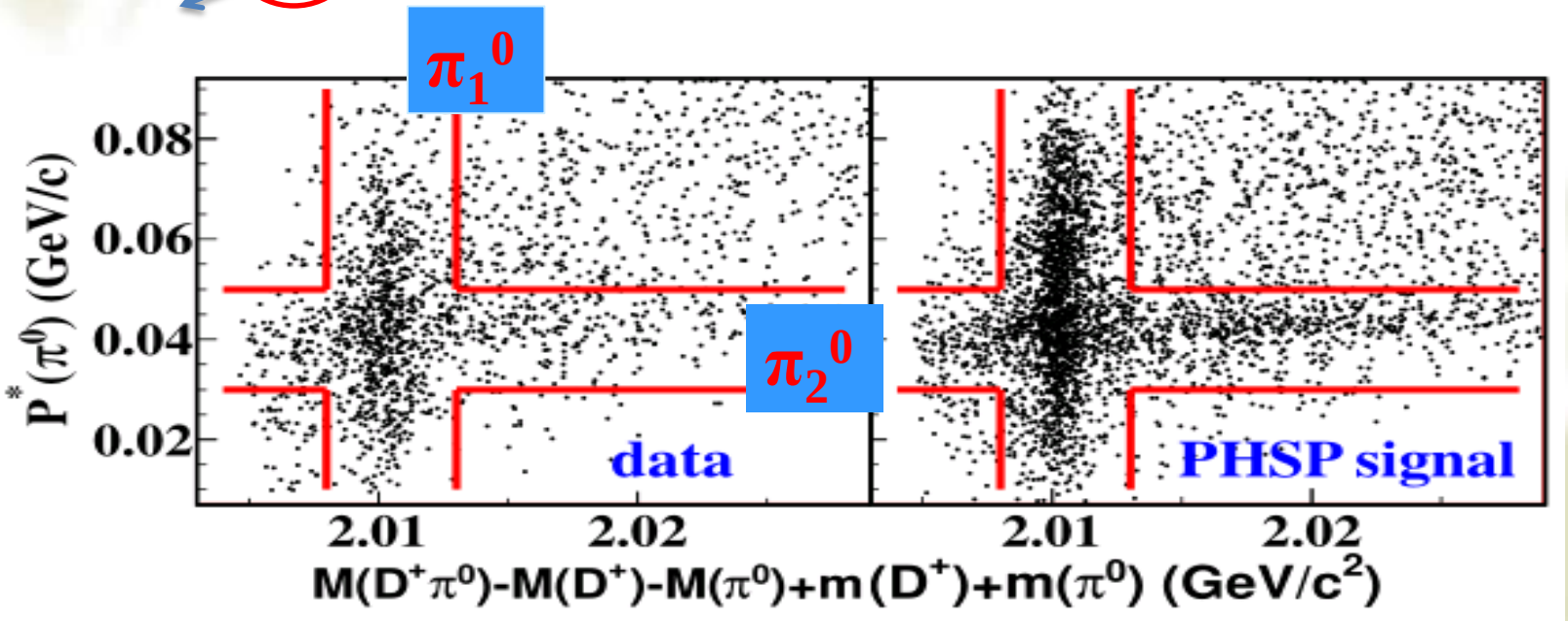
To tag a D^+ through $K^-\pi^+\pi^+$

RM(D^+): the recoil mass of D^+
M(D^+): the reconstructed mass
m(D^+): the mass taken in PDG

- *reject* $e^+e^- \to D^{(*)}\overline{D}^{(*)}$
- *keep only the three-body process* $e^+e^- \to \pi D^{(*)}\overline{D}^{(*)}$

To tag a π^0 in $D^{*+}D^{*0}\pi^-$



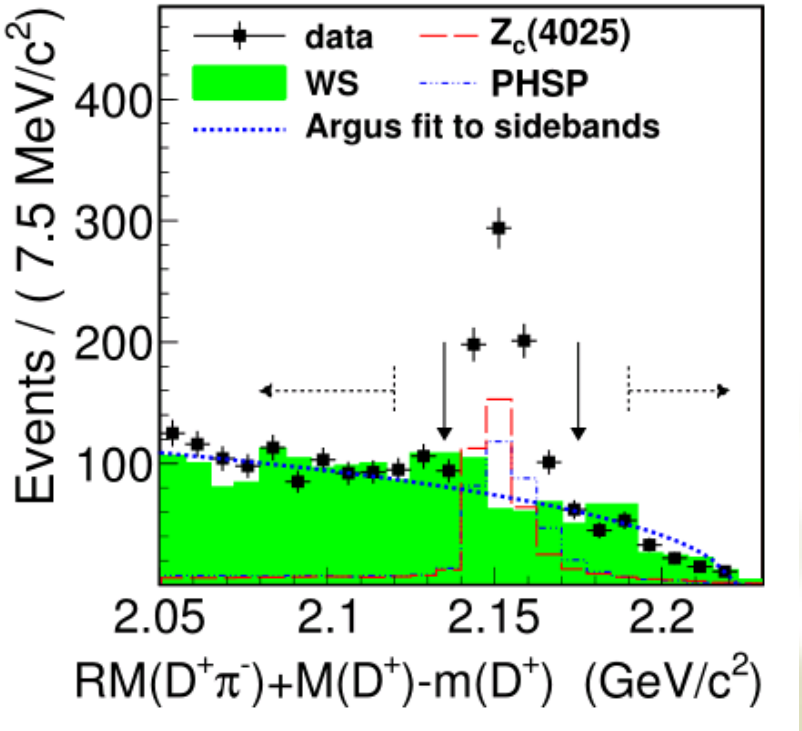


π^0 fulfills one of the below requirement

- momentum of π^0 in the recoil system of $D^+\pi^-$: **(0.03, 0.05) GeV/c**
- mass of $D^+\pi^0$: **(2.008, 2.013) GeV/c^2**

To select signals of $D^{*+}D^{*0}\pi^-$

- $\pi^{\pm}(D^{*}\bar{D}^{*})^{\mp}$ peaks ~2.15GeV in the $D^{+}\pi^{-}$ recoil mass spectrum
- a data-driven method to understand combinatorial backgrounds:
  shape is well reproduced by the WS shape

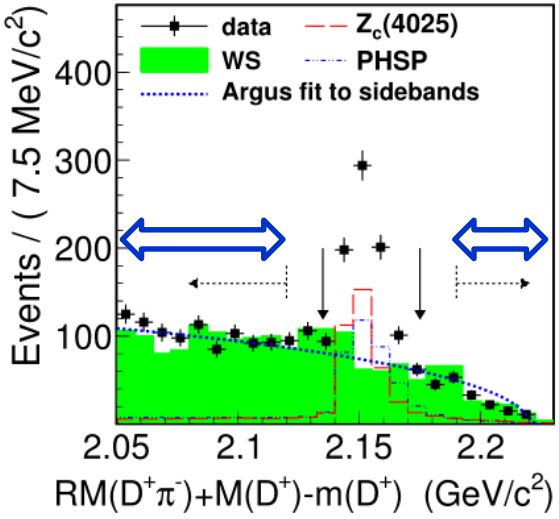


wrong-sign (WS) events

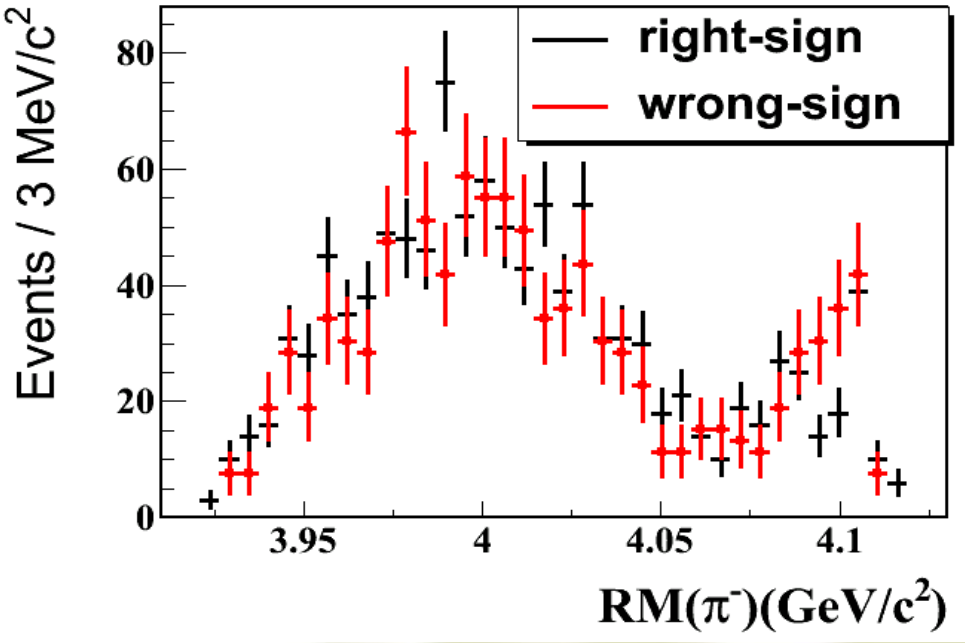
- to conserve charge and charm number, *D^+ only associates with bachelor π^-*
- we assign a π^+ with *D^+* to form WS events

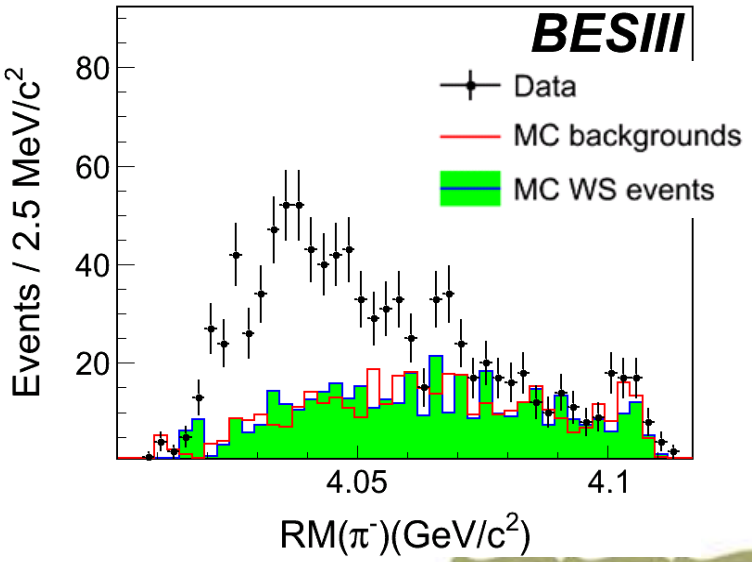
- very evident peak
- signal to background ratio is optimized

Is the WS shape good to describe the backgrounds ?



use control sample of the sidebands in RM($D^+\pi^-$) spectrum

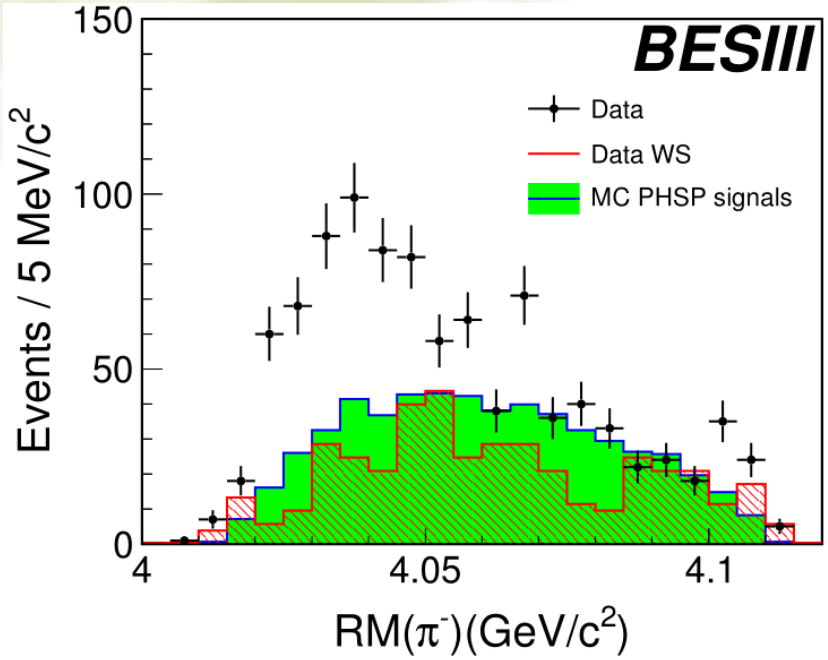




YES!

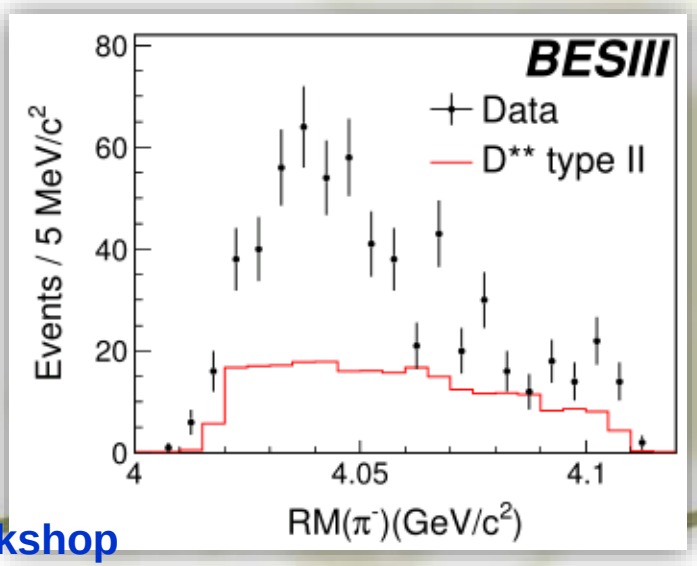
Both control sample of *RM($D^+\pi^-$)* sidebands and MC simulation demonstrate.

Evident enhancement in the π^- recoil mass spectrum



- ***clear enhancement*** of data over the WS shape
- cannot be interpreted with the three-body process of $e^+e^- \to D^{*+}\bar{D}^{*0}\pi^-$ (PHSP signals)
- the $e^+e^- \to$ D**D* $\to \pi$D*D* processes do not peak under the enhancement

PHSP signal normalized to the size difference between data and the WS backgrounds

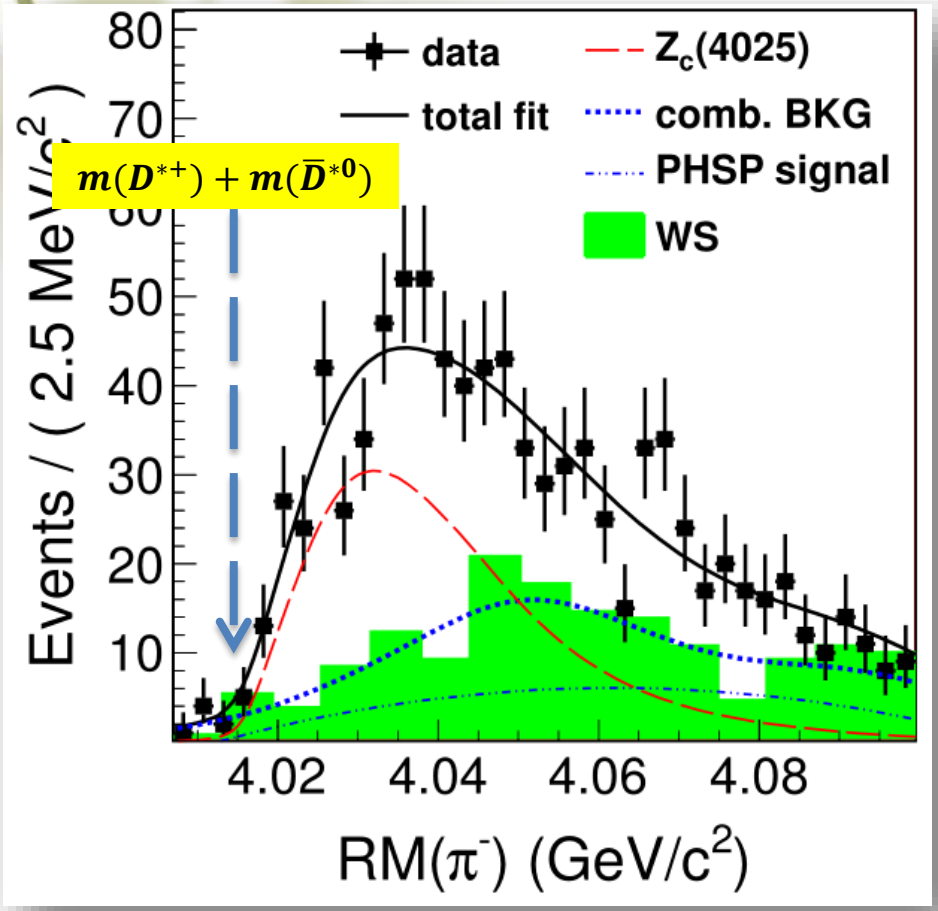


What do we learn

- Do you clearly see $e^+e^- \to \pi^\pm(D^*\overline{D}^*)^\mp$ events? **Yes**
- Can the WS shape represent the combinatorial backgrounds? **Yes**
- Do you see an excess of data over the backgrounds? **Yes**
- Is the enhancement due to the $e^+e^- \to D^{*+}\overline{D}^{*0}\pi^-$ non-resonant process? **NO**
- Is the enhancement due to the $e^+e^- \to D^*D^{**}$, $D^{**} \to D^*\pi$ resonant process? **NO**
- Can we try the assumption of $e^+e^- \to \pi^\pm Z'c^\pm$, $Z'c^\pm \to (D^*\overline{D}^*)^\mp$ to interpret it?

I guess this is the only remaining option …

Measurement of the enhancement



assume it as a particle, Zc(4025), and fit to the π^- recoil mass distribution

- ✓ **Zc(4025) signal**: S-wave relativistic Breit-Wigner function with phase-space factor
- ✓ **three-body process (PHSP)**
- ✓ **combinatorial backgrounds**: the **WS** shape

significance is > 10σ
χ^2/ndf= 30.4/33 = 0.92

resonance parameter:

$$m(Z_c(4025)) = 4026.3 \pm 2.6 \pm 3.7\,\mathrm{MeV/c^2},$$
$$\Gamma(Z_c(4025)) = 24.8 \pm 5.6 \pm 7.7\,\mathrm{MeV}.$$

Properties on the $Zc^+(4025)$

$$
\begin{aligned}
m(Z_c(4025)) &= 4026.3 \pm 2.6 \pm 3.7\,\mathrm{MeV/c^2}, \\
\Gamma(Z_c(4025)) &= 24.8 \pm 5.6 \pm 7.7\,\mathrm{MeV}.
\end{aligned}
$$

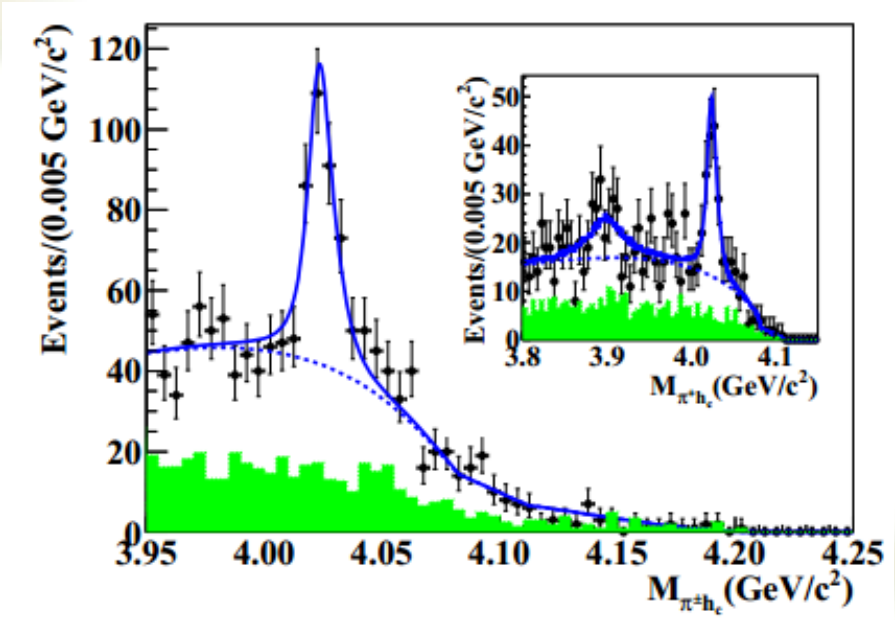
- only a few MeV higher than the threshold of $\boldsymbol{D^{*+}\bar{D}^{*0}}$ (4017Mev/c2)
- (at least) four quark states
- higher state of $Z^+c(3900)$?
- not (significantly) observed in the process of $e^+e^- \to \pi^+\pi^- J/\psi$ at $\sqrt{s} = 4.26GeV$ ***Phys. Rev. Lett(2013) 252001***
- a particle? a molecule-like D*-D* bound states? or other scenarios?
- search for other decay modes can help to pin down its properties: $\pi^+\psi(2S), \pi^+h_c(1P)$ ... *stay tuned*

Accepted by PRL

Mass spectra of $\pi^{\pm}h_c$

Observed Z⁺c(4020)

Accepted by PRL

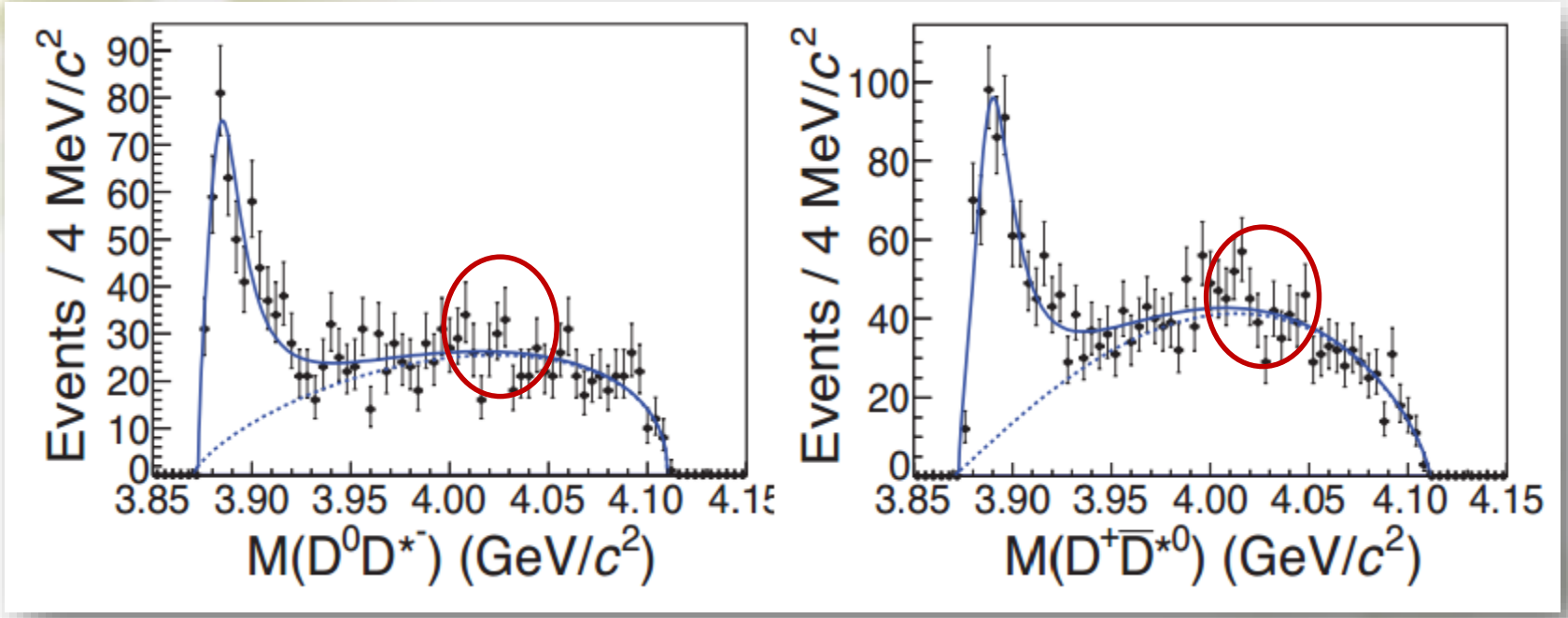


	Z⁺c(4025)	Z⁺c(4020)
Mass (MeV)	4026.3±2.6±3.7	4022.9±0.8±2.7
Width (MeV)	24.8±5.6±7.7	7.9±2.7±2.6
$\frac{Br(Z_c'^+ \to D^{*+}\bar{D}^{*0})}{Br(Z_c'^+ \to \pi^+ h_c)}$	~12	

Mass spectra of $(D\bar{D}^*)^{\pm}$

at 4.26GeV

arXiv: 1310.1163



Observed $Z^+c(3885)$!!!

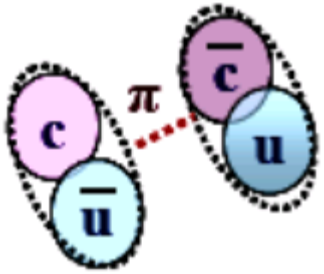
Tag	$M_{\rm pole}(\mathrm{MeV}/c^2)$	$\Gamma_{\rm pole}(\mathrm{MeV})$	Z_c signal (evts)	χ^2/ndf
π^+D^0	3882.3 ± 1.5	24.6 ± 3.3	502 ± 41	54/54
π^-D^+	3885.5 ± 1.5	24.9 ± 3.2	710 ± 54	60/54

Any signature of around 4025MeV?

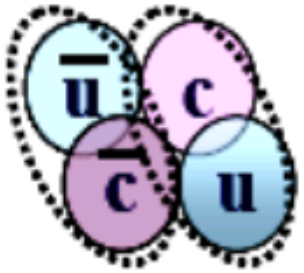
The nature of the $Zc^+(4025)$

arXiv:*1308.2760*

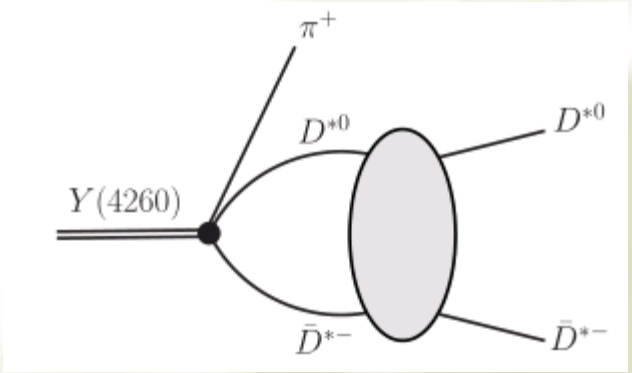
1. Hadronic molecules



2. Tetraquarks



3. Initial Single Pion Emission (ISPE) model



4. ...

Summary

- We observed a charged charmonium-like resonant structure Zc(4025) in $e^+e^- \rightarrow \pi^- D^{*+}\underline{D}^{*0}$ (*c.c.*) at the center-of-mass energy 4.26GeV (significance > **10σ**)
  - an exotic state with at least four-quark constituent
- The resonance parameter is measured to be

$$\begin{aligned} m(Z_c(4025)) &= 4026.3 \pm 2.6 \pm 3.7\,\mathrm{MeV/c^2}, \\ \Gamma(Z_c(4025)) &= 24.8 \pm 5.6 \pm 7.7\,\mathrm{MeV}. \end{aligned}$$

- We are now at the beginning stage of great impacts on X/Y/Z states from BESIII
  - more results will come out …

Thanks!

谢 谢！

Especially to the staff of BEPCII and the computing center, the funding agencies, and all the friends of BES!