Risultati recenti nella fisica di BESIII

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On behalf of the BESIII Collaboration

Incontri di Fisica delle Alte Energie
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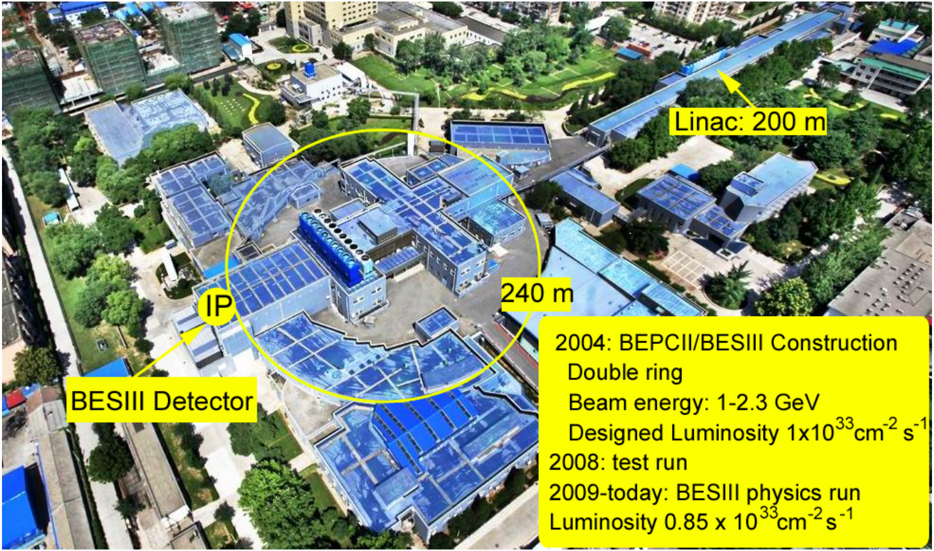
Genova

Outline

- The BESIII experiment
- Selected results from:
  - Charm Physics
  - Charmonium Spectroscopy
- Conclusions

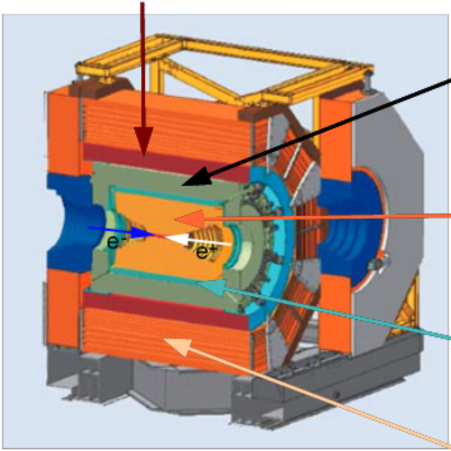
Beijing Electron Positron Collider II



The BESIII detector

Nucl. Instr. Meth. A614, 345 (2010)

1T superconducting magnet



EMC:
- CsI (Tl) calorimeter
- Energy resolution < 2.5% at 1 GeV (barrel)
- Energy resolution < 5% at 1 GeV (end caps)
- Spatial resolution $\sigma(xy)$: 6 mm at 1 GeV

MDC: (Drift Chamber)

- Spatial resolution $\sigma(r\Phi)$ = 130 μm (single wire)
- Momentum resolution: 0.5% at 1 GeV

TOF
- $\sigma(t)$=90 ps (barrel)
- $\sigma(t)$=120 ps (end caps)

Muon ID (RPC)
- 8 layers (end caps) + 9 layers (barrel)
- $\Delta\Omega/4\pi$=93%

BESIII physics program

- Light hadron Physics
  - Meson and baryon spectroscopy
  - Multiquark states
  - Threshold effects
  - Glueballs and hybrids
  - Two-photon physics
  - Form factors
- QCD and τ
  - Precision R measurement
  - τ decay
- Charmonium physics
  - Precision spectroscopy
  - Transitions and decays
- XYZ meson physics
  - Y(4260), Y(4360) properties
  - $Z_c(3900)^+, \ldots$
- Charm physics
  - Semi-leptonic form factors
  - Decay constants f_D and f_{D_s}
  - CKM matrix: $|V_{cd}$ and $|V_{cs}|$
  - D^0-$\bar{D}^0$ mixing, CPV
  - Strong phases
- Precision mass measurements
  - τ mass
  - D, D^* mass

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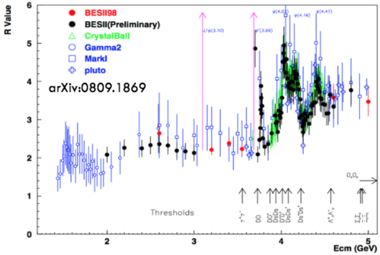
Data samples

Data sample	E_{cm}	Years
1.3×10^9	J/ψ at 3.097 GeV	2009 (0.225×10^9) + 2012
0.5×10^9	$\psi(2S)$ at 3.686 GeV	2009 (0.106×10^9) + 2012
2.92 fb^{-1}	$\psi(3770)$ at 3.773 GeV	2010+2011
0.5 fb^{-1}	$\psi(4040)$ at 4.009 GeV	2011
0.024 fb^{-1}	τ mass scan at around 3.554 GeV	2011
1.9 fb^{-1}	Y(4260) at 4.23 GeV and 4.26 GeV	2013
0.5 fb^{-1}	Y(4360) at 4.36 GeV	2013
0.5 fb^{-1}	Y(4260) and Y(4360) scan	2013
0.8 fb^{-1}	R scan, 104 energy points between 3.85 and 4.59 GeV	2014
1.0 fb^{-1}	at 4.42 GeV	2014
0.1 fb^{-1}	at 4.47 GeV and 4.53 GeV for line shape	2014
0.04 fb^{-1}	at 4.575 GeV (around the threshold of Lambda Charm)	2014
0.5 fb^{-1}	at 4.60 GeV	2014



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Charmonium spectroscopy

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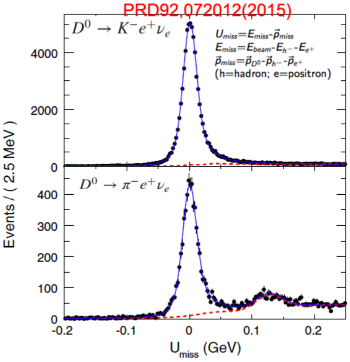
Charm physics

Charm Physics

- Study of dynamics of $D^0 \to K^- e^+ \nu$) and $D^0 \to \pi^- e^+ \nu$) decays (PRL92,072012(2015))
- Study of decay dynamics and CP asymmetry in $D^+ \to K_L e^+ \nu_e$ decays (PRD92,112008(2015))
- Measurement of the form factors in the decay $D^+ \to \omega e^+ \nu_e$ and search for the decay $D^+ \to \phi e^+ \nu$ (PRD92,071101R(2015))
- Search for $D^0 \to \gamma\gamma$ and improved measurement of the branching fraction for $D^0 \to \pi^0 \pi^0$ (PRD91,112015(2015))
- Measurement of the Absolute Branching Fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$ (PRL115,221805(2015))
- Measurement of the Absolute Hadronic Branching Fraction for Λ_c^+ Baryon (PRD116,052001(2016))

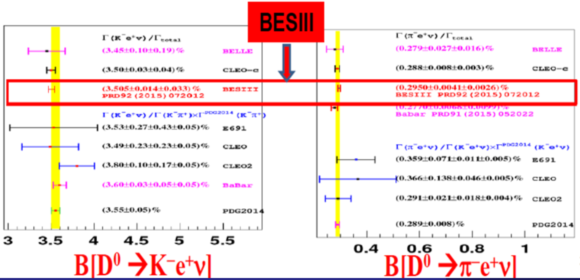
- Many other results not covered in this talk:
  - Measurement of y_{CP} in $D^0 \bar{D}^0$ oscillation using quantum correlations in $e^+ e^- \to D^0 \bar{D}^0$ (PLB744,339(2015))
  - Study of $D^+ \to K^- \pi^+ e^+ \nu_e$ (arXiv:1512.08627)
  - ....

Measurement of $\mathcal{B}(D^0 \to K^-(\pi^-)e^+\nu_e)$ - PRD92,072012(2015)



Direct measurements of the absolute branching fractions for $D^0 \to K^- e^+ \nu_e$ and $D^0 \to \pi^- e^+ \nu_e$ decays using 2.92 fb^{-1} taken at 3.773 GeV.

$\mathcal{B}(D^0 \to K^- e^+ \nu)=(3.505\pm0.014\pm0.033)\%$
$\mathcal{B}(D^0 \to \pi^- e^+ \nu)=(0.2950\pm0.0041\pm0.0026)\%$



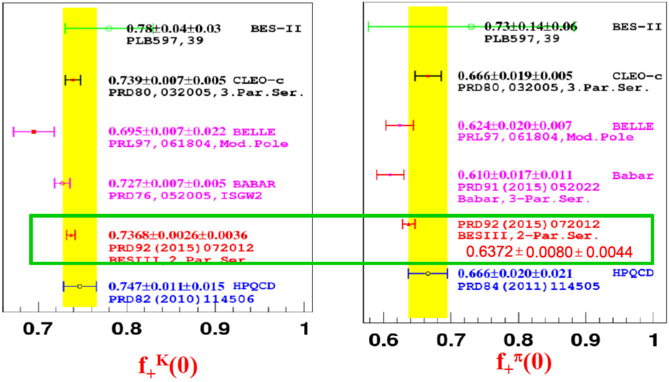
Measurement of $f_+^{K(\pi)}(0)$ - PRD92,072012(2015)

From a study of the differential decay rates they obtain the products of hadronic form factor and the magnitude of the CKM matrix element:

$$f_+^K(0)|V_{cs}|=0.7172\pm0.0025\pm0.0035$$
$$f_+^\pi(0)|V_{cd}|=0.1435\pm0.0018\pm0.0009$$

Combining these products with the values of $|V_{cs(d)}|$ from the SM constraint fit (PDG):

$$f_+^K(0)=0.7368\pm0.0026\pm0.0036$$
$$f_+^\pi(0)=0.6372\pm0.0080\pm0.0044$$



Study of $D^+ \to K_L e^+\nu_e$; $D^+ \to \omega e^+\nu_e$; $D^+ \to \phi e^+\nu_e$

Using 2.92 fb^{-1} of electron-positron annihilation data collected at $\sqrt{s}$ =3.773 GeV, they obtained the first measurements of (PRD92,112008 (2015)):

$$\mathcal{B}(D^+ \to K^0_L e^+\nu_e) = (4.481 \pm 0.027 \pm 0.103)\%$$

CP asym. $A_{CP}^{D^+ \to K_L e^+\nu_e}$=(-0.59±0.60±1.48)%

Product of hadronic from factor and the magnitude of the CKM element:

$$f^K_+(0)|V_{cs}| = 0.728 \pm 0.006 \pm 0.011$$

$f^K_+(0) = 0.748 \pm 0.007 \pm 0.012$ using $|V_{cs}|$ from the SM constrained fit

Using 2.92 fb^{-1} of electron-positron annihilation data collected at $\sqrt{s}$ =3.773 GeV, they obtained an improved measurements of (PRD92,071101R(2015)):

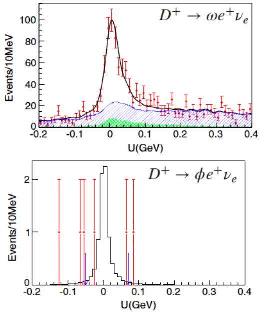
$$\mathcal{B}(D^+ \to \omega e^+\nu_e) = (1.63 \pm 0.11 \pm 0.08) \times 10^{-3}$$

The parameters defining the corresponding hadronic from factor ratios at zero momentum transfer are determined for the first time:

$$r_V = V(0)/A_1(0) = 1.24 \pm 0.09 \pm 0.06$$
$$r_2 = A_2(0)/A_1(0) = 1.06 \pm 0.15 \pm 0.05$$

They also searched for the decay $D^+ \to \phi e^+\nu_e$:

$$\mathcal{B}(D^+ \to \phi e^+\nu_e) < 1.3 \times 10^{-5}$$



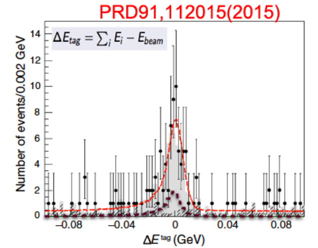
PRD92,071101R(2015)

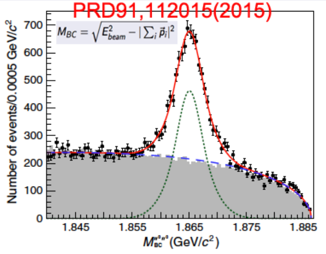
Search for $D^0 \to \gamma\gamma$ and measurement of $\mathcal{B}(D^0 \to \pi^0\pi^0)$

Using 2.92 fb^{-1} of electron-positron annihilation data collected at $\sqrt{s}$ =3.773 GeV, they searched for the flavor-changing neutral current process $D^0 \to \gamma\gamma$ using a double-tag technique.

No signal has been found

$\mathcal{B}(D^0 \to \gamma\gamma) < 3.8 \times 10^{-6}$ at 90% CL





Using 2.92 fb^{-1} of electron-positron annihilation data collected at $\sqrt{s}$ =3.773 GeV, they obtained an improved measurements of:

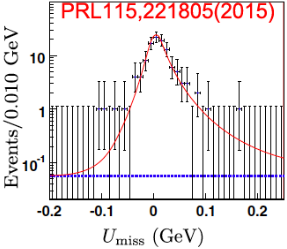
$$\mathcal{B}(D^0 \to \pi^0\pi^0)=(8.24\pm0.21\pm0.30)\times10^{-4}$$

Precise measurement of the $\mathcal{B}(D^0 \to \pi^0\pi^0)$ can improve understanding of SU(3) flavor symmetry breaking effect in D^0 decays, benefiting theoretical predictions of CP violation in D decays.

Measurement of the Absolute Branching Fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$

Using 567 pb^{-1} of electron-positron annihilation data collected at $\sqrt{s}$ =4.599 GeV, they reported the first measurement of the absolute branching fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$.

$$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$$

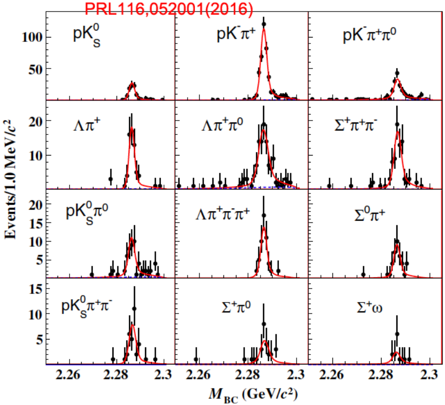


An accurate measurement of $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ is a key ingredient in calibrating LQCD calculations, which, will play an important role in understanding different Λ_c^+ semileptonic decays.

Theoretical predictions: 1.4%-9.2%
[PRD40,2955(1989), PRD40,2944(1989), PRD43,2939(1991), PRD45,3266(1992), PRD53,1457(1996), PLB431,173(1998), PRD60,034009(1999), PRC72,035201(2005)]
PDG2015:(2.9±0.5)% [Belle PRL113,042002(2014): $\mathcal{B}(\Lambda_c^+ \to pK^- \pi^+) = (6.84^{+0.32}_{-0.40})\%$]

Measurement of the Absolute Hadronic Branching Fraction for Λ_c^+ Baryon (PRL116,052001(2016))

- The first measurement of absolute hadronic branching fractions of Λ_c^+ baryon at the $\Lambda_c^+\bar{\Lambda}_c{}^-$ product threshold.
- 12 Cabibbo-favored Λ_c^+ hadronic decay modes are analyzed with a double-tag technique, based on a sample of 567 pb^{-1} collected at $\sqrt{s}$ =4.6 GeV.
- A global least-squares fitter is utilized to improve the measured precision.

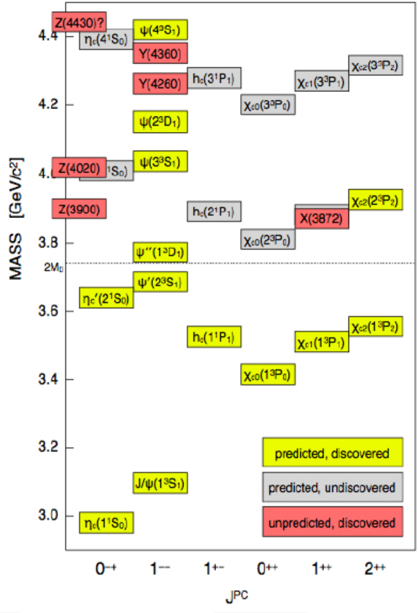


Mode	This work (%)	PDG (%)
pK^0_S	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3
$pK^0_S\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50
$pK^0_S\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0

Charmonium Spectroscopy

- Observation of the $\psi(1^3D_2)$ State in $e^+e^- \to \pi^+\pi^-\gamma\chi_{c1}$ (PRL115,011803(2015))
- Search for the $Y(4140)$ via $e^+e^- \to \gamma\phi J/\psi$ (PRD91,032002(2015))
- Observation of $Z_c(3900)^\pm$ in $e^+e^- \to \pi^+\pi^- J/\psi$ (PRL110,252001(2013))
- Observation of $Z_c(3900)^0$ in $e^+e^- \to \pi^0\pi^0 J/\psi$ (PRL115,112003(2015))
- Confirmation of a charged charmoniumlike state $Z_c(3885)^\mp$ in $e^+e^- \to \pi^\pm(D\bar{D}^*)^\mp$ with double D tag (PRD92,092006(2015))
- Observation of $Z_c(3885)^0$ in $e^+e^- \to \pi^0(D\bar{D}^*)^0$ (PRL115,222002(2015))
- Observation of $Z_c(4020)^{\pm,0}$ in $e^+e^- \to \pi^{+,0}\pi^{-,0}h_c$ (PRL111,242001(2013), PRL113,212002(2014))
- Observation of $Z_c(4025)^{\pm,0}$ in $e^+e^- \to \pi^\pm(D^*\bar{D}^*)^{\mp,0}$ (PRL112,132001(2014), PRL115,182002(2015))

- Many other results not covered in this talk:
  - Observation of $e^+e^- \to \gamma X(3872)$ - PRL 112, 092001(2014)
  - Observation of $e^+e^- \to \omega\chi_{c0}$ - PRL 114, 092003 (2015)
  - Observation of $Z_c(3885)^\mp$ with single D tag (PRL112,022001(2014))
  - ....



- Below the $D\bar{D}$ threshold, all expected states have been observed, with properties in good agreement with theory.
- Many unexpected states have been reported above the $D\bar{D}$ threshold (XYZ). Several exotic hypotheses as to their nature: tetraquarks, hadronic molecules, hybrids, glueballs, hadro-quarkonia.

X states:

- charmonium-like states with $J^{PC} \neq 1^{--}$
- Observed in B decays, pp and $p\bar{p}$ collisions

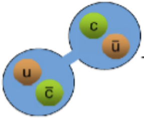
Y states:

- charmonium-like states with $J^{PC} = 1^{--}$
- Observed in direct e^+e^- annihilation or in ISR

Z states:

- charmonium-like states carrying electric charge
- Must contain at least a $c\bar{c}$ and a light $q\bar{q}$ pair

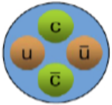
Exotic charmonium-like states interpretation



Molecular state

Loosely bound state of a pair of mesons.
The dominant binding mechanism should be pions echange

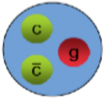
NA Tornqvist PLB 590, 209 (2004)
ES Swanson PLB 598,197 (2004)
E Braaten & T Kusunoki
PRD 69 074005 (2004)
CY Wong PRC 69, 055202 (2004)
MB Voloshin PLB 579, 316 (2004)
F Close & P Page PLB 578,119 (2004) ....



Tetraquark

Bound state of four quarks, i.e. diquark-antidiquark
Distinctive feature of multi-quark picture with respcet to charmonium:
- Prediction of many new states
- Possible existence of new states with nonzero charge, strangeness or both

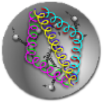
L Maiani et al PRD 71,014028 (2005)
T-W Chiu & TH Hsieh PRD 73, 111503 (2006)
D Ebert et al PLB 634, 214 (2006)
...



Charmonium Hybrids

Bound states with a pair of quarks and one excited gluon
Lattice and model predictions found that the lowest charmonium hybrids lies around 4200 MeV

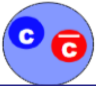
P Lacock et al (UKQCD) PLB 401, 308 (1997)
SL Zhu PLB 625, 212 (2005)
FE Close, PR Page PLB 628, 215 (2005)
E Kou, O Pene PLB 631, 164 (2005)
...



Glueball

Bound states of gluons

N. Brambilla et al., Eur. Phys. J. C71: 1534, 2011

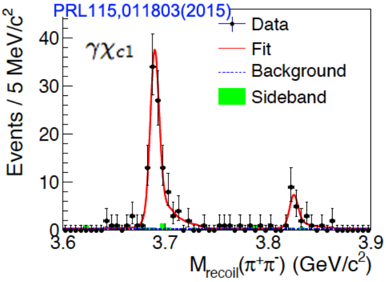


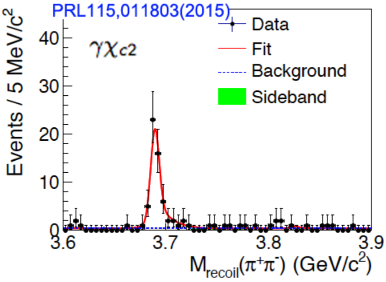
Conventional charmonium

C Meng & KT Chao PRD 75, 114002 (2007)
W Dunwoodie & V Ziegler PRL 100 062006 (2008)
O Zhang, C Meng & HQ Zheng arXiv:0901.1553

Observation of $e^+e^- \to \pi^+\pi^- X(3823)$ - PRL115,011803(2015)

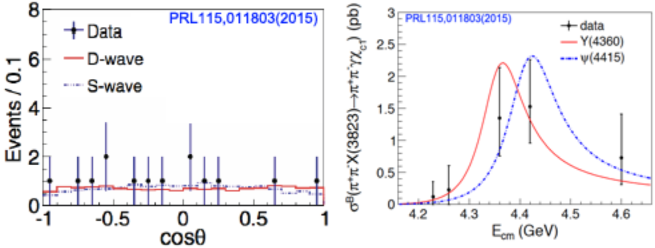
- The X(3823) was discovered by Belle in $B \to \chi_{c1}\gamma K$, PRL 111,032001(2013). Mass and width consistent with the missing $\psi(1^3D_2)$ state
- BESIII: Study of $e^+e^- \to \pi^+\pi^- X(3823)$, $X(3823) \to \gamma\chi_{c1,c2}$ at center of mass energies from 4.19 to 4.6 GeV, with 4.67 fb^{-1}.





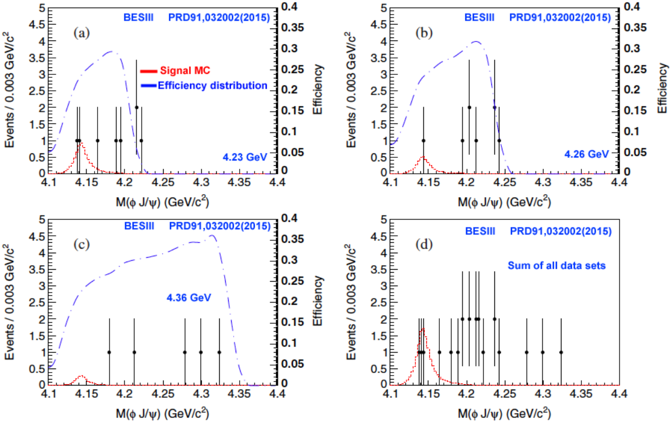
- The X(3823) is observed with significance 6.2σ in $\chi_{c1}\gamma$
- m=3821.7$\pm$1.3$\pm$0.7 MeV/c^2
- Γ <16 MeV at 90% CL

Observation of $e^+e^- \to \pi^+\pi^- X(3823)$ - PRL115,011803(2015)



- The X(3823) is a good candidate for the ψ_2 charmonium state with $J^{PC} = 2^{--}$
  - Mass and width are in agreement with potential model prediction for 1^3D_2
  - not enough statistics to distinguish between D- and S-wave hypothesis
- The fit of the energy-dependent cross section for the process is compatible with both Y(4360) and $\psi(4415)$ line shapes

- The Y(4140) was discovered by CDF in $B^+ \to \phi J/\psi K^+$, PRL102,242002 (2009).
- Not observed by Belle (PRL104,112004(2010)), BABAR (PRD91,012003(2015)) and LHCb (PRD85,091103(2012).
- Enhancement observed recently by CMS (PLB734, 261(2014)) and D0 (PRD89,012004(2014))
- BESIII: Search for $Y(4140)$ decays into $\phi J/\psi$ through the process $e^+e^- \to \gamma\phi J/\psi$ with 1094 pb^{-1} at 4.23 GeV, 827 pb^{-1} at 4.26 GeV and 545 pb^{-1} at 4.36 GeV



Search for the Y(4140) via $e^+e^- \to \gamma\phi J/\psi$ - PRD91,032002 (2015)

No significant signal found at BESIII

$$\sigma^B \cdot \mathcal{B} = \sigma(e^+e^- \to \gamma Y(4140)) \cdot \mathcal{B}(Y(4140) \to \phi J/\psi):$$

at 4.23 GeV: <0.35 pb at 90% CL
at 4.26 GeV: <0.28 pb at 90% CL
at 4.36 GeV: <0.33 pb at 90% CL

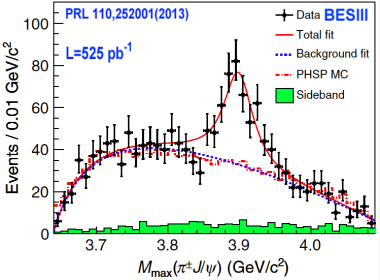
The UL are of the same order of magnitude as
$\sigma^B \cdot \mathcal{B} = \sigma(e^+e^- \to \gamma X(3872)) \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ [PRL 112, 092001]:
at 4.23 GeV: $0.27 \pm 0.09 \pm 0.02$ pb
at 4.26 GeV: $0.33 \pm 0.12 \pm 0.02$ pb

Considering:
$\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$=5% arXiv:0910.3138
$\mathcal{B}(Y(4140) \to \phi J/\psi) = 30\%$ PRD80, 054019 (molecular calculation)

$$\frac{\sigma^B(e^+e^- \to \gamma Y(4140))}{\sigma(e^+e^- \to \gamma X(3872))} \leq 0.1 \text{ at 4.23 and 4.26 GeV}$$

Discovery of the $Z_c(3900)^{\pm}$ - PRL 110, 252001 (2013)

- Study of the $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ process at the center of mass energy of 4.260 GeV using a 525 pb^{-1}
- Choosing the heavier J/ψ combination per events removes reflection at 3.45 GeV/c^2
- Unbinned maximum likelihood fit to the $\pi^{\pm} J/\psi$ invariant mass distribution

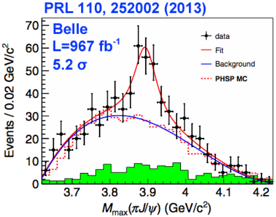


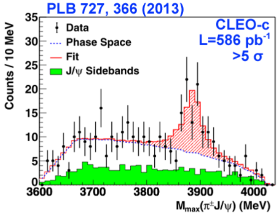
- Significance greater than 8σ
- m=$(3899.0\pm3.6\pm4.9)$ MeV/c^2
- $\Gamma=(46\pm10\pm20)$ MeV
- Mass close to the $D\bar{D}^*$ threshold
- Decays to $J/\psi \rightarrow$ contains $c\bar{c}$
- Electric charge $\rightarrow$ contains $u\bar{d}$
- 4-quark state?!

$$\frac{\sigma(e^+e^- \rightarrow \pi^{\pm} Z_c(3900)^{\mp} \rightarrow \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \rightarrow \pi^+\pi^- J/\psi)} = (21.5\pm3.3\pm7.2)\%$$

Belle: $e^+e^- \rightarrow \gamma_{ISR} J/\psi\pi^+\pi^-$
m=$(3894.5\pm6.6\pm4.5)$ MeV/c^2
$\Gamma=(63\pm24\pm26)$ MeV

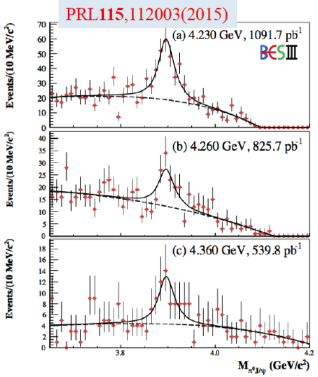
CLEO-c: $e^+e^- \rightarrow J/\psi\pi^+\pi^-$ at 4.17 GeV
m=$(3886\pm4\pm2)$ MeV/c^2
$\Gamma=(37\pm4\pm8)$ MeV

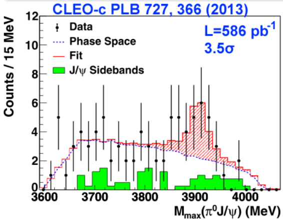




- Observation of the $Z_c(3900)^0$ decaying into $J/\psi\pi^0$ in $e^-e^- \to \pi^0\pi^0 J/\psi$ using 2.5 fb^{-1} data sample
- Simultaneous fit to the $J/\psi\pi^0$ invariant mass distributions for the three data samples:
$\sqrt{s}$ =4.230 GeV, 4.260 GeV, 4.360 GeV

m=3894.8±2.3±3.2 MeV/c^2;
Γ=29.6±8.2±8.2 MeV;
Significance greater than 10σ



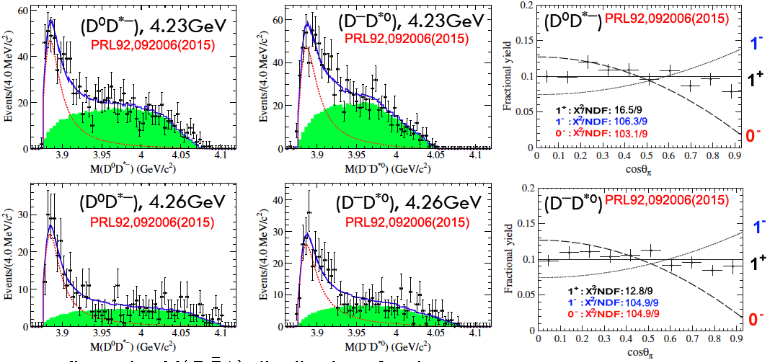


- First evidence by CLEO-c
- $e^+e^- \to J/\psi\pi^+\pi^-$ at 4.17 GeV
- m=3904±4±5 MeV/c^2
- Γ=37 (Fixed) MeV
- Significance 3.7σ

Isospin triplet is established!

Confirmation of $Z_c(3885)^{\pm}$ in $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$ using double D tag method - PRD92,092006(2015)

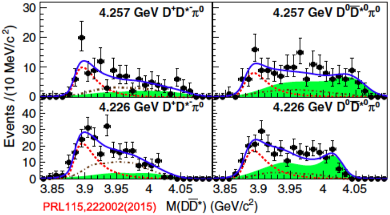
- Combined study of the processes $e^+e^- \to \pi^+ D^0 D^{*-}$ ($\pi^+ D^0 \bar{D}^0$-tag.) and $e^+e^- \to \pi^+ D^- D^{*0}$ ($\pi^+ D^- D^0$-tag.) using 1090 pb^{-1} at $\sqrt{s}$ =4.23 GeV and 827 pb^{-1} at $\sqrt{s}$=4.26 GeV.
- Double tag method: reconstruction of the bachelor π and $D\bar{D}$ pair: this allows to use more D decays modes and effectively suppresses background.



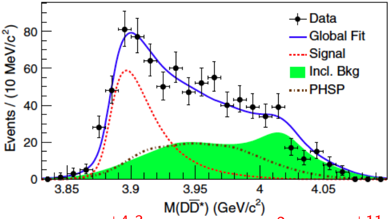
- Simultaneous fit to the $M(D\bar{D}^*)$ distributions for the two processes.
- m=3881.7±1.6±1.6 MeV/c^2; Γ=26.6±2.0±2.1 MeV; Significance $> 10\sigma$
- The angular distribution is consistent with $J^P = 1^+$.
- The results are consistent with single D tag results (PRL112,022001(2014)).

Search for $Z_c(3885)^0$ in $e^+e^- \to \pi^0(D\bar{D}^*)^0$ - PRL115,222002(2015)

- Study of the processes $e^+e^- \to \pi^0(D\bar{D}^*)^0$, where $(D\bar{D}^*)^0$ refers to D^+D^{*-} or $D^0\bar{D}^{*0}$ using 1092 pb^{-1} at $\sqrt{s}$ =4.23 GeV and 826 pb^{-1} at $\sqrt{s}$=4.26 GeV.



State	$m_{\rm pole}$(MeV/c^2)	$\Gamma_{\rm pole}$(MeV)	
$Z_c(3885)^+$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$	PRL112,022001(2014)
$Z_c(3885)^+$	$3881.7 \pm 1.6 \pm 2.1$	$26.6 \pm 2.0 \pm 2.3$	PRD92,092006 (2015)
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	PRL115,222002(2015)

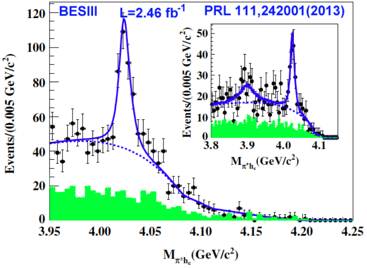


- m=3885.7$^{+4.3}_{-5.7}$ $\pm$ 8.4 MeV/c^2; Γ=35$^{+11}_{-12}$$\pm$15 MeV; Significance $>$ 10σ

Favours the assumption that $Z_c(3885)^0$ is the neutral isospin partner of $Z_c(3885)^\pm$

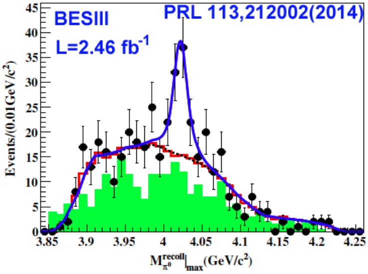
Observation of $Z_c(4020)^{\pm,0}$ in $e^+e^- \to \pi^{+,0}\pi^{-,0}h_c$

-Study of $e^+e^- \to \pi^{+,0}\pi^{-,0}h_c$ at center of mass energies from 3.90 to 4.42 GeV.
- $h_c \to \gamma\eta_c$; η_c reconstructed in 16 hadronic decay modes



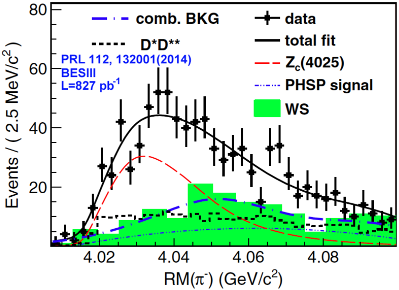
- Simultaneous fit to the $M_{\pi^\pm h_c}$ distributions at 4.23, 4.26 and 4.36 GeV using 2.46 fb^{-1}.
- A structure, $Z_c(4020)^\pm$ is observed with significance $> 8.9\sigma$
- m=4022.9±0.8±2.7 MeV/c^2
- Γ=7.9±2.7±2.6 MeV

- Simultaneous fit to the $M^{recoil}_{\pi^0}$ distributions at 4.23, 4.26 and 4.36 GeV using 2.46 fb^{-1}.
- A structure, $Z_c(4020)^0$ is observed with significance $> 5\sigma$
- m=4023.9±2.2±3.8 MeV/c^2
- Width is fixed to be the same as its charged partner



Another isospin triplet is established!

Observation of $Z_c(4025)^{\pm,0}$ in $e^+e^- \to \pi^\pm(D^*\bar{D}^*)^{\mp,0}$

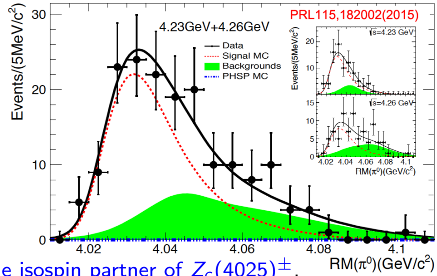


-Study of $e^+e^- \to \pi^\pm(D^*\bar{D}^*)^\mp$ at 4.26 GeV using 827 pb^{-1}.

- Unbinned maximum likelihood fit to the $M^{recoil}_{\pi^-}$ distribution.
- A structure, $Z_c(4025)^+$ is observed with significance 10σ
- $m=4026.3\pm2.6\pm3.7$ MeV/c^2
- $\Gamma=24.8\pm5.6\pm7.7$ MeV

-Study of $e^+e^- \to \pi^0(D^*\bar{D}^*)^0$ at 4.26 GeV using 1092 pb^{-1} at $\sqrt{s}$=4.23 GeV and 826 pb^{-1} at $\sqrt{s}$=4.26 GeV.

- Unbinned maximum likelihood fit to the $M^{recoil}_{\pi^0}$ distribution.
- A structure, $Z_c(4025)^0$ is observed with significance 7.4σ
- $m=4025.5^{+2.0}_{-4.7}\pm3.1$ MeV/c^2
- $\Gamma=23.0\pm6.0\pm1.0$ MeV



$Z_c(4025)^0$ state is a good candidate to be the isospin partner of $Z_c(4025)^\pm$.
Parameters very similar to $Z_c(4020)$ → needed rigorous spin analysis.

Summary on Z_c states

State	Process $e^+e^- \to$	Decay Mode	Mass (MeV/c^2)	Width (MeV)	Ref
$Z_c(3900)^{\pm}$	$\pi^+\pi^- J/\psi$	$J/\psi\pi^{\pm}$	3899.0±3.6±4.9	46±10±20	PRL110,252001(2013)
$Z_c(3900)^0$	$\pi^0\pi^0 J/\psi$	$J/\psi\pi^0$	3894.8±2.3±3.2	29.6±8.2±8.2	PRL115,112003(2015)
$Z_c(3885)^{\pm}$	$\pi^{\pm}(D\bar{D}^*)^{\mp}$	D^0D^{*-} $D^+\bar{D}^{*0}$	3883.9±1.5±4.2	24.8±3.3±11.0	PRL112,022001(2014) Single D tag
$Z_c(3885)^{\pm}$	$\pi^{\pm}(D\bar{D}^*)^{\mp}$	D^0D^{*-} $D^-\bar{D}^{*0}$	3881.7±1.6±1.6	26.6±2.0±2.1	PRD92,092006(2015) Double D tag
$Z_c(3885)^0$	$\pi^0(D\bar{D}^*)^0$	D^+D^{*-} $D^0\bar{D}^{*0}$	$3885.7^{+4.3}_{-5.7}8.4$	$35^{+11}_{-12}\pm15$	PRL115,222002(2015)
$Z_c(4020)^{\pm}$	$\pi^+\pi^- h_c$	$h_c\pi^{\pm}$	4022.9±0.8±2.7	7.9±2.7±2.6	PRL111,242001(2013)
$Z_c(4020)^0$	$\pi^0\pi^0 h_c$	$h_c\pi^0$	4023.9±2.2±3.8	Fixed	PRL113,212002(2014)
$Z_c(4025)^{\pm}$	$\pi^{\mp}(D^*\bar{D}^*)^{\pm}$	$D^{*+}\bar{D}^{*0}$ $D^{*-}D^{*0}$	4026.3±2.6±3.7	24.8±5.6±7.7	PRL112,132001(2014)
$Z_c(4025)^0$	$\pi^0(D^*\bar{D}^*)^0$	$D^{*0}\bar{D}^{*0}$ $D^{*+}D^{*-}$	$4025.5^{+2.0}_{-4.7}\pm3.1$	23.0±6.0±1.0	PRL115,182002(2015)

Conclusion

- BESIII is successfully operating since 2008, and continues to take data
- It is an excellent laboratory to study charm and charmonium spectroscopy:
  - High statistics
  - Low background
- Many interesting results have been obtained, only few of them are covered in this talk
  - "Form factor of baryons and light hadrons" - Poster by Piero Patteri
- Future:
  - More data will be collected
  - Higher luminosity is expected from BEPCII
  - More detailed studies will be done

THANKS FOR YOUR ATTENTION!

BACKUP SLIDES

In the limit of zero positron mass, the differential rate for $D^0 \to K^-(\pi^-)e^+\nu_e$ decay is given by

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{cs(d)}|^2|\vec{p}_{K^-(\pi^-)}|^3|f_+^{K(\pi)}(q^2)|^2, \qquad (1.1)$$

where G_F is the Fermi coupling constant, $\vec{p}_{K^-(\pi^-)}$ is the three-momentum of the $K^-(\pi^-)$ meson in the rest frame of the D^0 meson, and $f_+^{K(\pi)}(q^2)$ represents the hadronic form factors of the hadronic weak current that depend on the square of the four-momentum transfer $q = p_{D^0} - p_{K^-(\pi^-)}$. These form factors describe strong interaction effects that can be calculated in lattice quantum chromodynamics (LQCD).

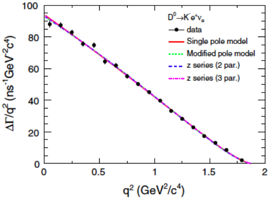


FIG. 6 (color online). Differential decay rates for $D^0 \to K^- e^+ \nu_e$ as a function of q^2. The dots with error bars show the data and the lines give the best fits to the data with different form-factor parametrizations.

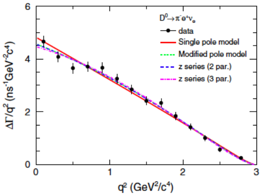


FIG. 7 (color online). Differential decay rates for $D^0 \to \pi^- e^+ \nu_e$ as function of q^2. The dots with error bars show the data and the lines give the best fits to the data with different form-factor parametrizations.

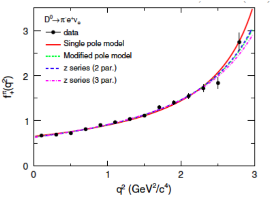


FIG. 9 (color online). Projections on $f_+^\pi(q^2)$ for $D^0 \to \pi^- e^+ \nu_e$.

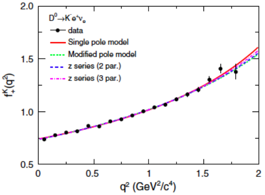


FIG. 8 (color online). Projections on $f_+^K(q^2)$ for $D^0 \to K^- e^+ \nu_e$.

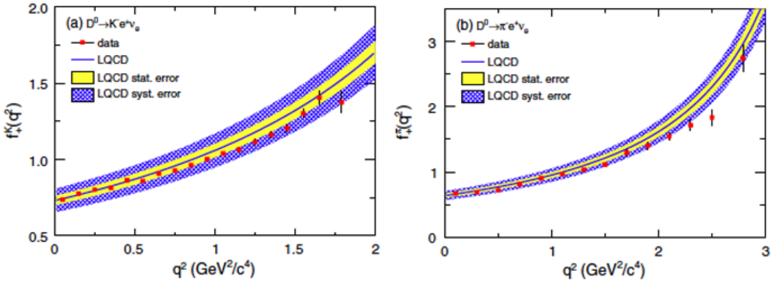


FIG. 10 (color online). Comparisons of the measured form factors (squares with error bars) with the LQCD calculations [26] (solid lines present the central values, bands present the LQCD uncertainties).

Study of $D^+ \to K_L e^+\nu_e$; $D^+ \to \omega e^+\nu_e$; $D^+ \to \phi e^+\nu_e$

$$A_{CP} \equiv \frac{\mathcal{B}(D^+ \to K_L^0 e^+\nu_e) - \mathcal{B}(D^- \to K_L^0 e^-\bar{\nu}_e)}{\mathcal{B}(D^+ \to K_L^0 e^+\nu_e) + \mathcal{B}(D^- \to K_L^0 e^-\bar{\nu}_e)} = (-0.59 \pm 0.60 \pm 1.48)\%. \quad (8)$$

This result is consistent with the theoretical prediction in Ref. [4] (-3.3×10^{-3}).

$$\frac{d\Gamma}{dq^2 d\cos\theta_1 d\cos\theta_2 d\chi dm_{\pi\pi\pi}} = \frac{3}{8(4\pi)^4} G_F^2 |V_{cd}|^2 \frac{p_\omega q^2}{M_D^2} \mathcal{B}(\omega \to \pi\pi\pi) |\mathcal{BW}(m_{\pi\pi\pi})|^2 [(1+\cos\theta_2)^2 \sin^2\theta_1 |H_+(q^2, m_{\pi\pi\pi})|^2$$
$$+ (1-\cos\theta_2)^2 \sin^2\theta_1 |H_-(q^2, m_{\pi\pi\pi})|^2 + 4\sin^2\theta_2 \cos^2\theta_1 |H_0(q^2, m_{\pi\pi\pi})|^2$$
$$+ 4\sin\theta_2(1+\cos\theta_2)\sin\theta_1\cos\theta_1\cos\chi H_+(q^2, m_{\pi\pi\pi}) H_0(q^2, m_{\pi\pi\pi})$$
$$- 4\sin\theta_2(1-\cos\theta_2)\sin\theta_1\cos\theta_1\cos\chi H_-(q^2, m_{\pi\pi\pi}) H_0(q^2, m_{\pi\pi\pi})$$
$$- 2\sin^2\theta_2 \sin^2\theta_1 \cos 2\chi H_+(q^2, m_{\pi\pi\pi}) H_-(q^2, m_{\pi\pi\pi})], \quad (2)$$

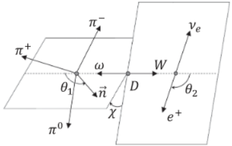


FIG. 3. Definitions of the helicity angles in the decay $D^+ \to \omega W^+$, $\omega \to \pi^+\pi^-\pi^0$, $W^+ \to e^+\nu_e$ for the three-body (θ_1) and two-body (θ_2) D^+-daughter decays, where both angles are defined in the rest frame of the decaying meson.

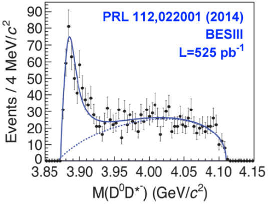
where G_F is the Fermi constant, p_ω is the ω momentum in the D rest frame, $\mathcal{B}(\omega \to \pi\pi\pi)$ is the branching fraction of $\omega \to \pi\pi\pi$, $m_{\pi\pi\pi}$ is the invariant mass of the three pions, and $\mathcal{BW}(m_{\pi\pi\pi})$ is the Breit-Wigner function that describes the ω line shape. The helicity amplitudes can in turn be related to the two axial-vector form factors $A_{1,2}(q^2)$ and the vector form factor $V(q^2)$. For the q^2 dependence, a single pole parametrization [24] is applied:

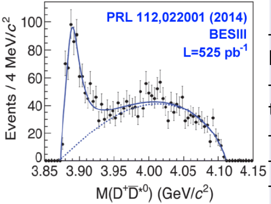
$$V(q^2) = \frac{V(0)}{1 - q^2/m_V^2}, \qquad A_{1,2}(q^2) = \frac{A_{1,2}(0)}{1 - q^2/m_A^2}, \quad (3)$$

where the pole masses m_V and m_A are expected to be close to $M_{D^*(1^-)} = 2.01$ GeV$/c^2$ and $M_{D^*(1^+)} = 2.42$ GeV$/c^2$ [13] for the vector and axial form factors, respectively. The ratios of these form factors, evaluated at $q^2 = 0$, $r_V = \frac{V(0)}{A_1(0)}$ and $r_2 = \frac{A_2(0)}{A_1(0)}$, are measured in this paper.

Observation of $Z_c(3885)^{\pm}$ in $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$ using single D tag method - PRL 112, 022001 (2014)

- Study of the $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$ at $\sqrt{s}$=4.26 GeV using a 525 pb^{-1}
- Single D tag method: Reconstruction of the π and one final state D meson; the presence of the $\bar{D}^*$ is inferred from energy-momentum conservation.
- $D^0 \to K^-\pi^+$; $D^+ \to K^-\pi^+\pi^-$





- Enhancement at $D\bar{D}^*$ threshold in both channels - Significance $> 18\sigma$
- Fit function:Breit-Wigner+smooth threshold function
- m=(3883.9±1.5±4.2) MeV/c^2
- Γ=(24.8±3.3±11.0)MeV
- $\sigma \times \mathcal{B}$=(83.5±6.6±22.0) pb

Parameters similar to $Z_c(3900)$. A J^P quantum number determination for the $Z_c(3900)$ needed

Fit to angular distribution favours $J^P = 1^+$

If this is $Z_c(3900)^{\pm}$, the ratio of partial decay widths is:

$$\frac{\Gamma(Z_c(3885)\to D\bar{D}^*)}{\Gamma(Z_c(3900)\to \pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$$

This ratio is much smaller than typical values for decays of conventional charmonium states above the open charm threshold:

$$\frac{\Gamma(\psi(3770)\to D\bar{D})}{\Gamma(\psi(3770)\to \pi^+\pi^- J/\psi)} = 482 \pm 84$$

This suggests the influence of very different dynamics in the Y(4260)-$Z_c(3900)$ system