Recent results from BESIII experiment

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(On behalf of the BESIII collaboration)

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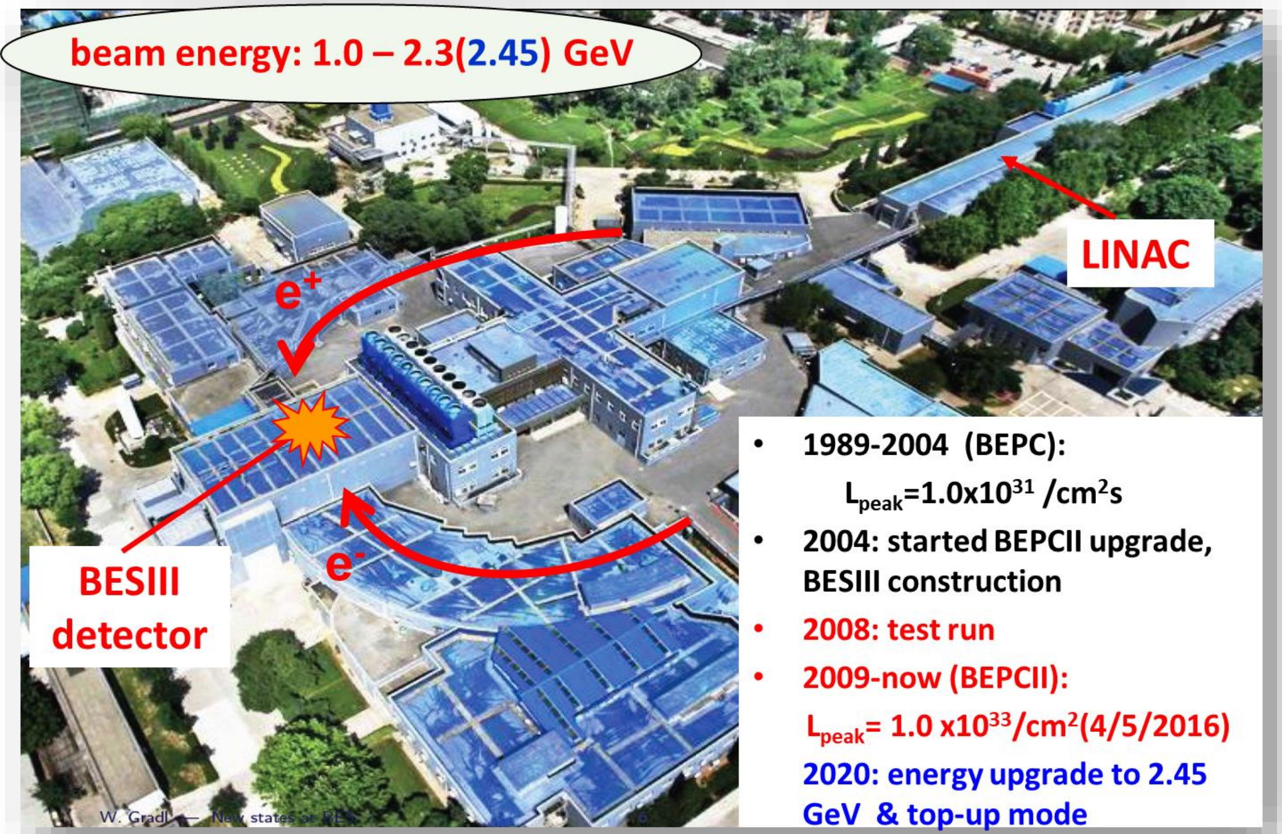
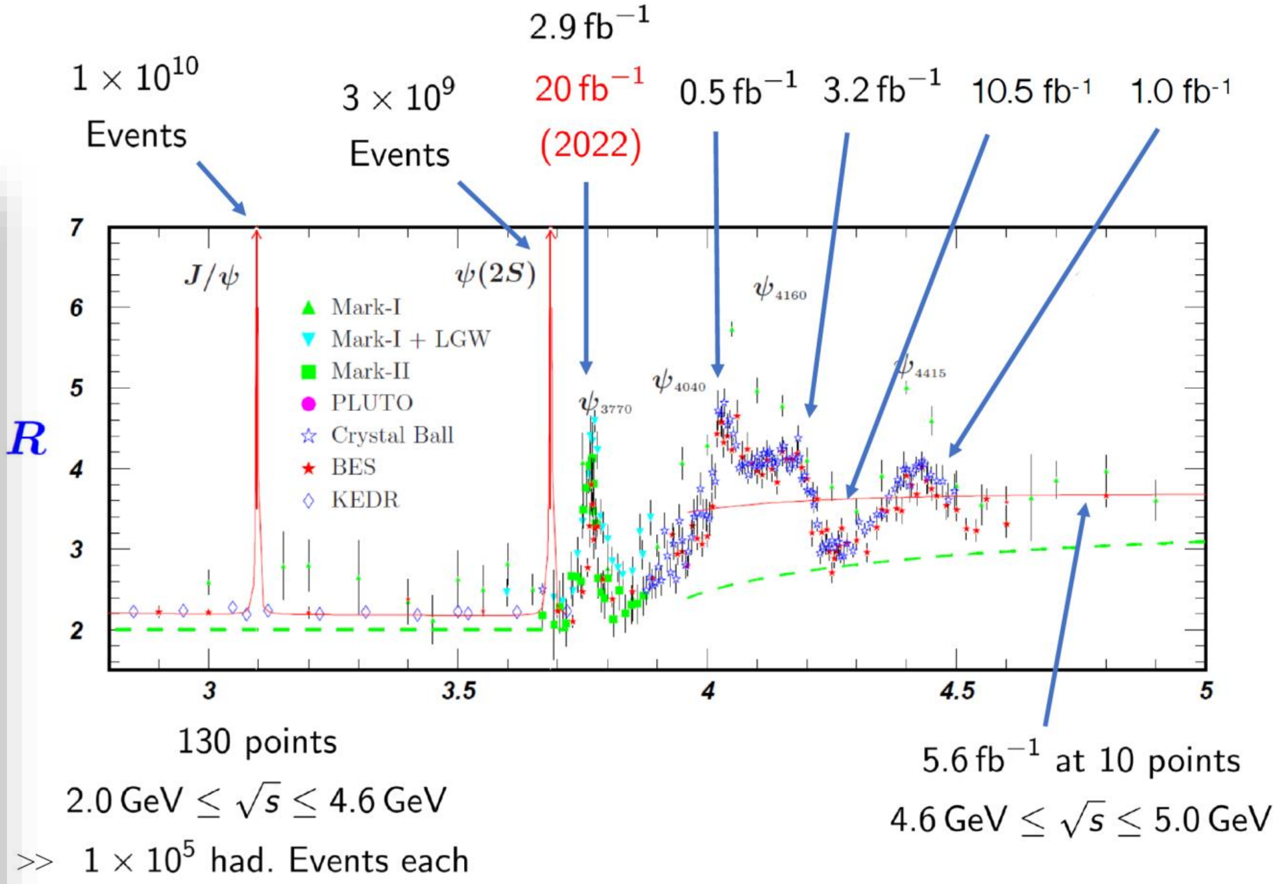
World's largest $\tau - \mathbf{charm}$ data sets in $\mathbf{e^+e^-}$ annihilation

Beijing Electron Positron Collider (BEPCII)



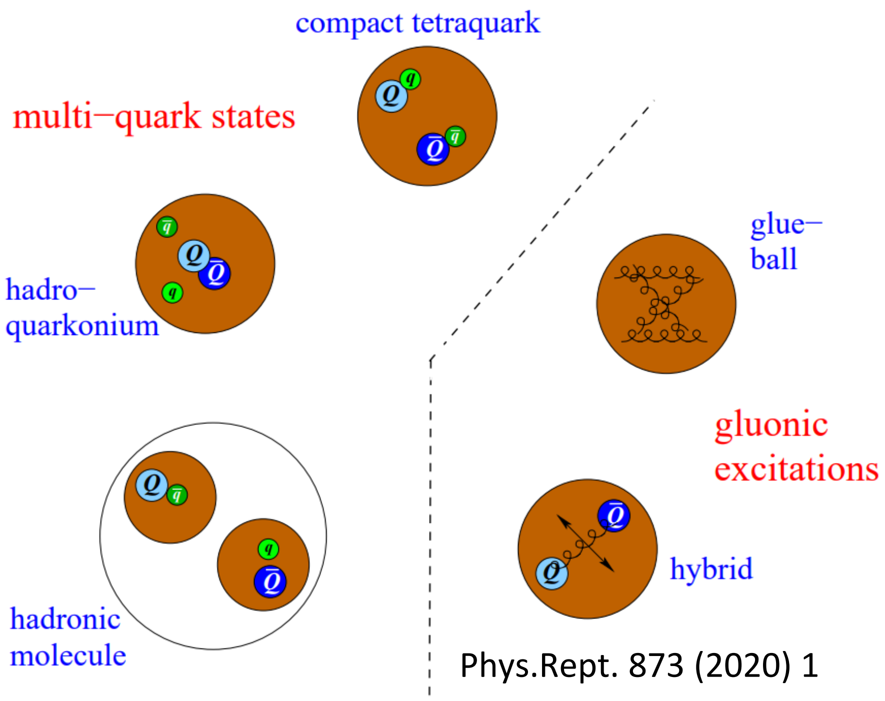
- **1989-2004 (BEPC):**
  L_{peak}=1.0x10^{31} /cm^{2}s
- **2004: started BEPCII upgrade, BESIII construction**
- **2008: test run**
- **2009-now (BEPCII):**
  L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)
  2020: energy upgrade to 2.45 GeV & top-up mode



Selected topics

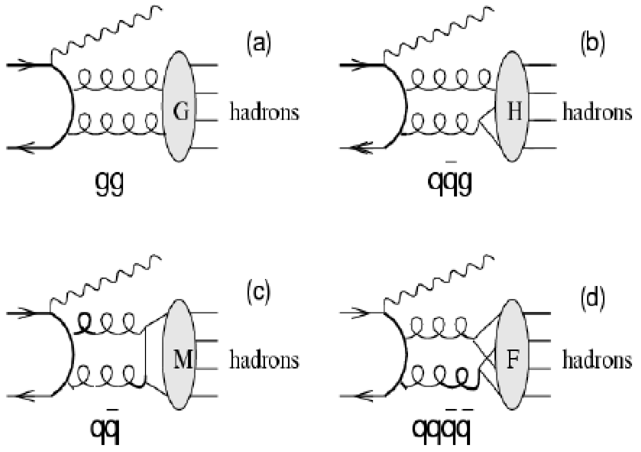
- Light hadrons: glueballs & more
- XYZ particles: Y(4260), X(3872), Zcs(3985)
- Charm decays: CKM, decay constants, form factors, LFU, $\Delta\delta_D$
- Baryons: form factors & polarization

Charmonium decays provide an ideal lab for light hadron physics



Phys.Rept. 873 (2020) 1

- Clean high statistics data samples
- Well defined initial and final states
  - Kinematic constraints
  - I(J^{PC}) filter
- "Gluon-rich" process



$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$

$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$

What's the role of gluonic excitation and how does it connect to the confinement?

Scalar glueball candidate

$$\Gamma(J/\psi \to \gamma G_{0^+}) = \frac{4}{27}\alpha \frac{|p|}{M_{J/\psi}^2}|E_1(0)|^2 = 0.35(8)keV$$

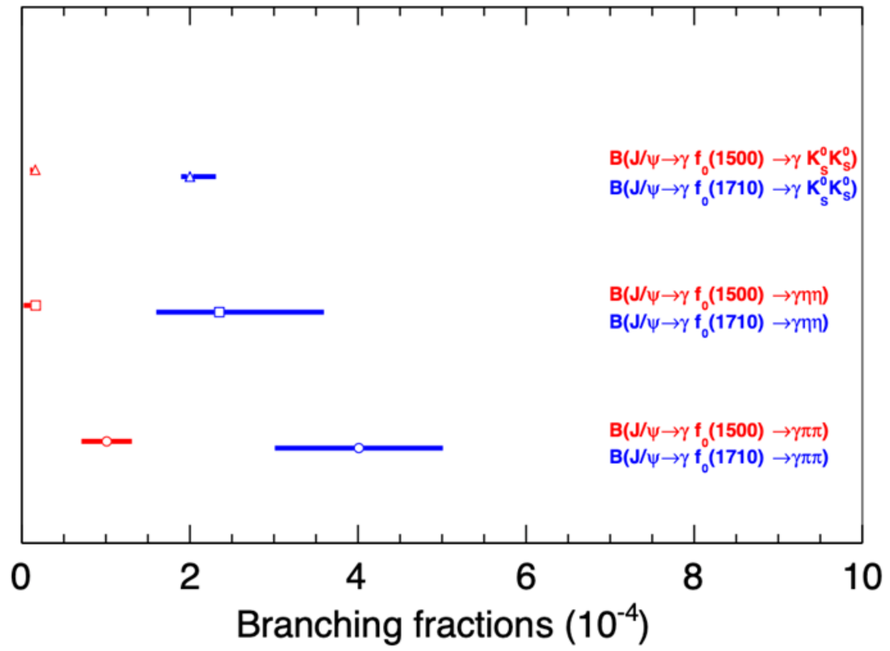
$$\Gamma/\Gamma_{tot} = 0.33(7)/93.2 = 3.8(9) \times 10^{-3}$$

CLQCD, Phys. Rev. Lett. 110, 021601 (2013)

Experimental results

- ➢B($J/\psi \to \gamma f_0(1710) \to \gamma K\bar{K}$)=($8.5^{+1.2}_{-0.9}$) $\times 10^{-4}$
- ➢B($J/\psi \to \gamma f_0(1710) \to \gamma\pi\pi$)=($4.0\pm1.0$)$\times 10^{-4}$
- ➢B($J/\psi \to \gamma f_0(1710) \to \gamma\omega\omega$)=($3.1\pm1.0$)$\times 10^{-4}$
- ➢B($J/\psi \to \gamma f_0(1710) \to \gamma\eta\eta$)=($2.35^{+0.13+1.24}_{-0.11-0.74}$)$\times 10^{-4}$

$\Rightarrow$ B($J/\psi \to \gamma f_0(1710)$) > 1.7×10^{-3}



$f_0(1710)$ largely overlapped with scalar glueball

Recent interpretations with coupled-channel analysis on BESIII results

Scalar isoscalar mesons and the scalar glueball from radiative J/ψ decays

Andrey V. Sarantsev, Igor Denisenko, Ulrike Thoma, Eberhard Klempt

A coupled-channel analysis of BESIII data on radiative J/ψ decays into $\pi\pi$, $K\bar{K}$, $\eta\eta$ and $\omega\phi$ has been performed. The partial-wave amplitude is constrained by a large number of further data. The analysis finds ten isoscalar scalar mesons. Their masses, widths and decay modes are determined. The scalar mesons are interpreted as mainly SU(3)-singlet and mainly octet states. Octet isoscalar scalar states are observed with significant yields only in the 1500-2100\,MeV mass region. Singlet scalar mesons are produced over a wide mass range but their yield peaks in the same mass region. The peak is interpreted as scalar glueball. Its mass and width are determined to $M = 1865$ \er25$^{+10}_{-30}$ {\rm MeV} and $\Gamma = 370$\er50$^{+30}_{-20}$ {\rm MeV}, its yield in radiative J/ψ decays to $(5.8 \pm 1.0)\ 10^{-3}$.

Comments: 11 pages, 4 figures
Subjects: **High Energy Physics - Phenomenology (hep-ph)**
DOI: 10.1016/j.physletb.2021.136227
Cite as: arXiv:2103.09680 **[hep-ph]**

Scalar and tensor resonances in J/ψ radiative decays

JPAC Collaboration: A. Rodas, A. Pilloni, M. Albaladejo, C. Fernandez-Ramirez, V. Mathieu, A. P. Szczepaniak

We perform a systematic analysis of the $J/\psi \to \gamma\pi^0\pi^0$ and $\to \gamma K^0_S K^0_S$ partial waves measured by BESIII. We use a large set of amplitude parametrizations to reduce the model bias. We determine the physical properties of seven scalar and tensor resonances in the 1-2.5 GeV mass range. These include the well known $f_0(1500)$ and $f_0(1710)$, that are considered to be the primary glueball candidates. The hierarchy of resonance couplings determined from this analysis favors the latter as the one with the largest glueball component.

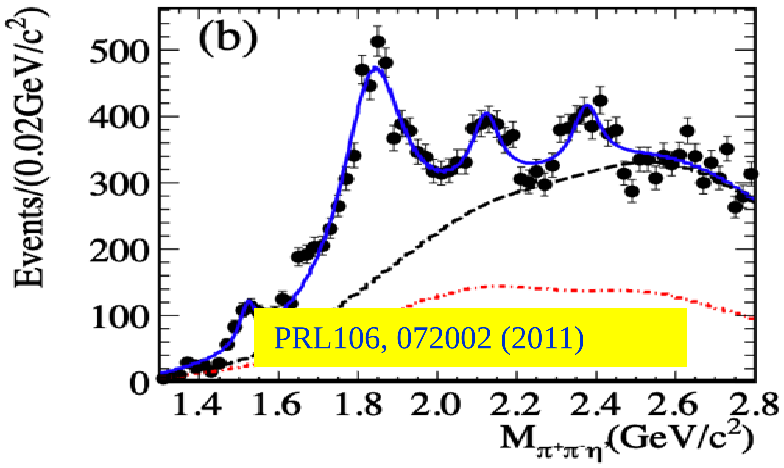
Comments: 17 pages, 11 figures + 28 pages of Supplemental Material
Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Physics - Experiment (hep-ex); Nuclear Theory (nucl-th)
Cite as: arXiv:2110.00027 **[hep-ph]**

To-do:

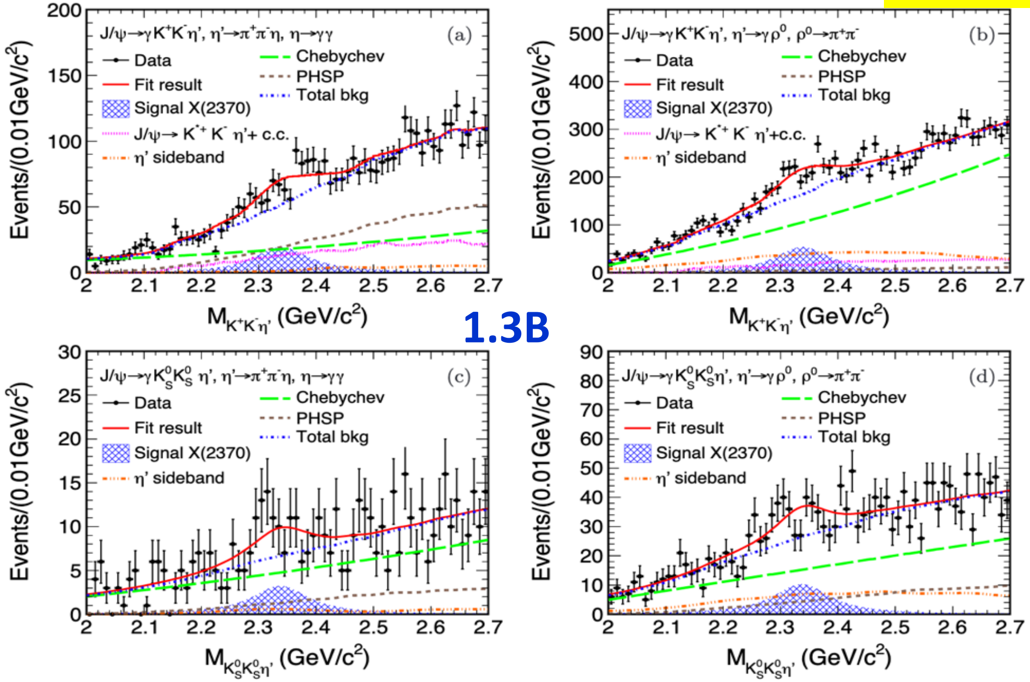
Implement those more sophisticated models in BESIII analysis

The X(2120) and X(2370)

- Observed in $J/\psi \to \gamma \eta' \pi^+ \pi^-$ at BESIII
  [PRL106, 072002 (2011)][PRL117, 042002(2016)]
- Combined analysis of $J/\psi \to \gamma K^+ K^- \eta'$ and $\gamma K_S K_S \eta'$
- Search for X(2370) in $J/\psi \to \gamma \eta \eta \eta'$

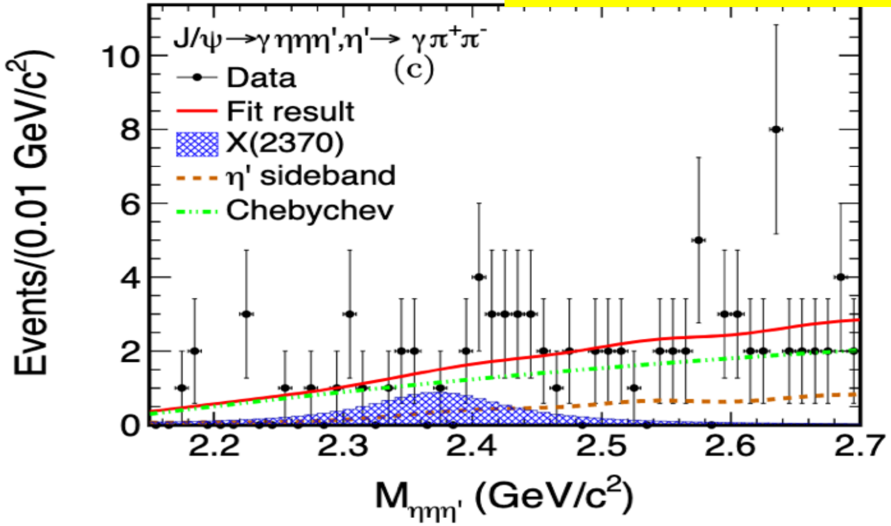


EPJC80,746(2020)



$$M_{X(2370)} = 2341.6 \pm 6.5(\text{stat.}) \pm 5.7(\text{syst.})\ \text{MeV}/c^2,$$
$$\Gamma_{X(2370)} = 117 \pm 10(\text{stat.}) \pm 8(\text{syst.})\ \text{MeV},$$

PRD103, 012009(2021)



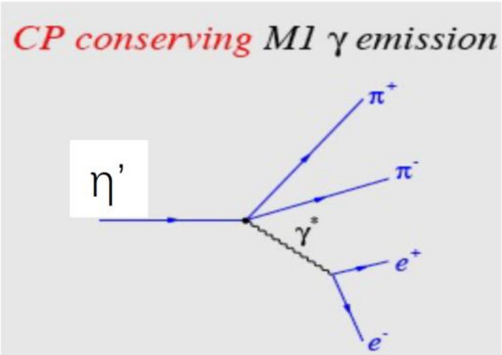
- Observation of $X(2370) \to K\bar{K}\eta'$, 8.3σ
- No evidence of $X(2120) \to K\bar{K}\eta'$
- No evidence of $X(2370) \to \eta\eta\eta'$

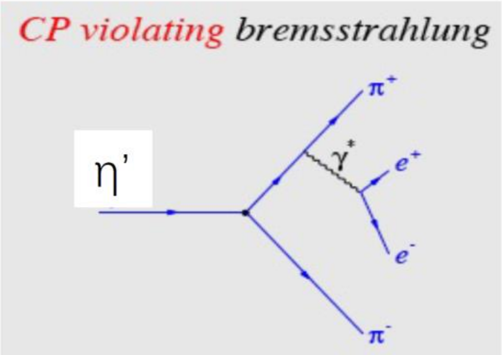
Search for CP violation in $\eta' \to \pi^+\pi^-e^+e^-$

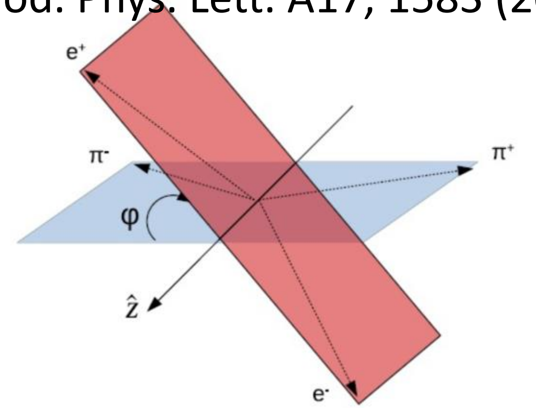
PRD 103,092005 (2021)

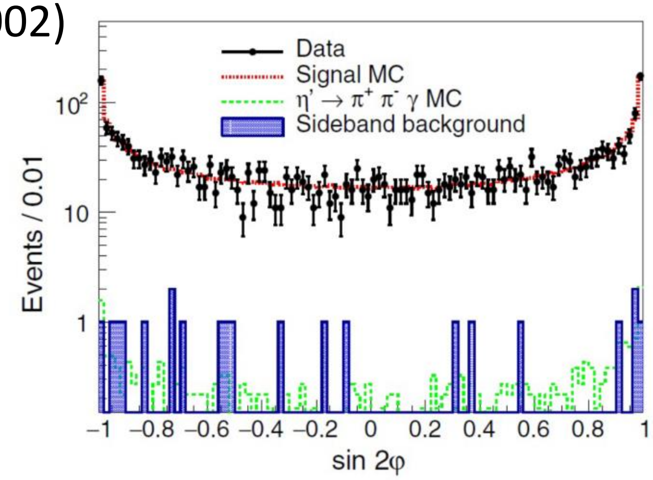
- Test of a new sources of CP violation beyond the CKM phase and outside flavor-changing processes
- CP asymmetry arises from the interference between the CP conserving magnetic and CP-violating electric transition

Mod. Phys. Lett.A17, 1489 (2002), Mod. Phys. Lett. A17, 1583 (2002)









$$\mathcal{A}_\varphi = \frac{N(\sin 2\varphi > 0) - N(\sin 2\varphi < 0)}{N(\sin 2\varphi > 0) + N(\sin 2\varphi < 0)} = (2.9 \pm 3.7_{\text{stat}} \pm 1.1_{\text{syst}})\%$$

- Consistent with 0 within uncertainties, no CP-violation
- Comparable precision to measurement of CP-asymmetry in $\mathrm{K_L} \to \pi^+\pi^-e^+e^-$ PRL. 84, 408(2000)

Selected topics

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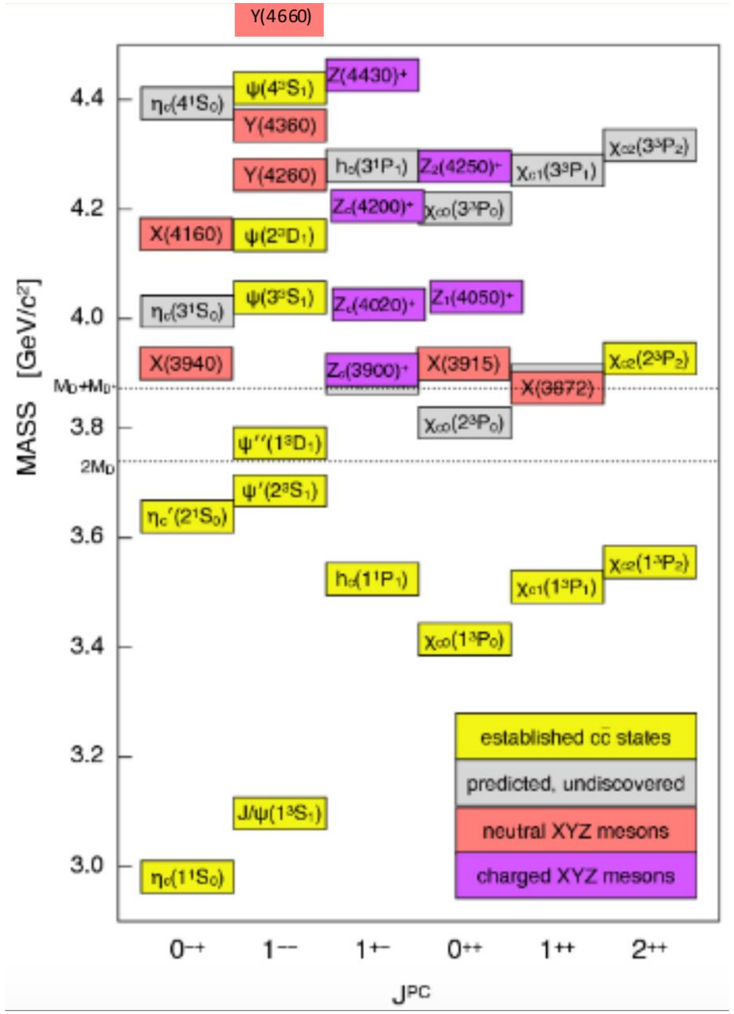
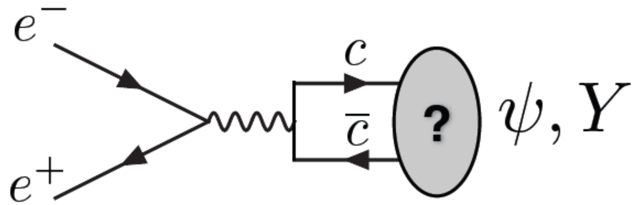
Charmonium and exotics at BESIII

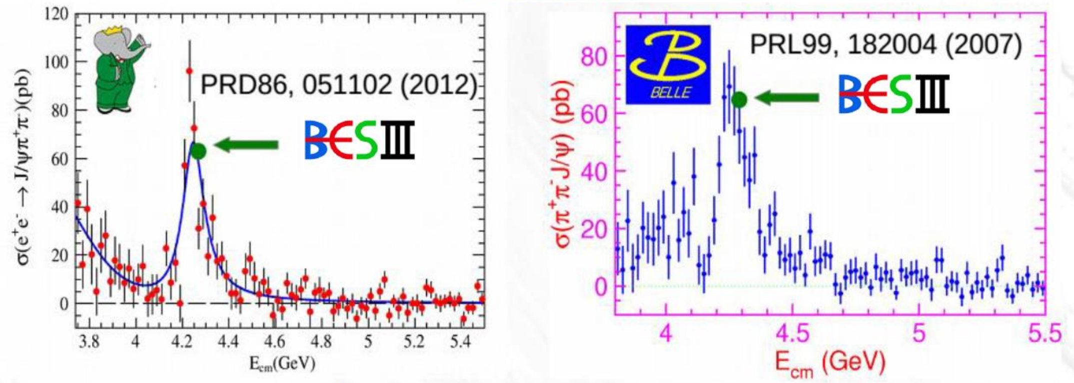




direct production of vectors: ψ , Y
radiative and hadronic transitions to others

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

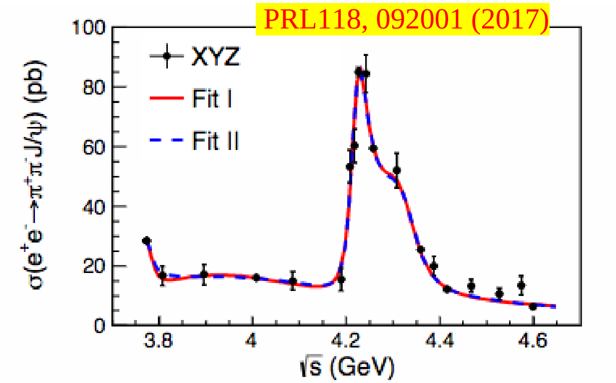
Compare running at **Belle and BaBar,** with one month at **BESIII !**

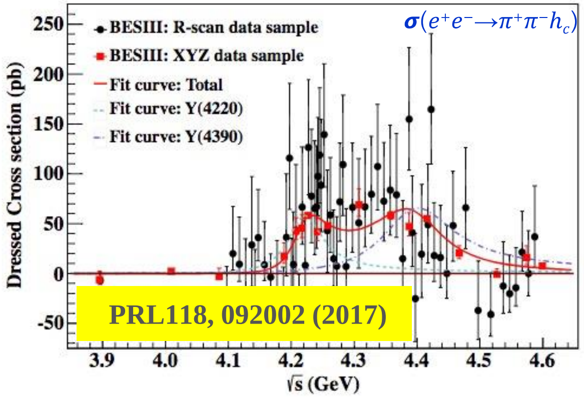


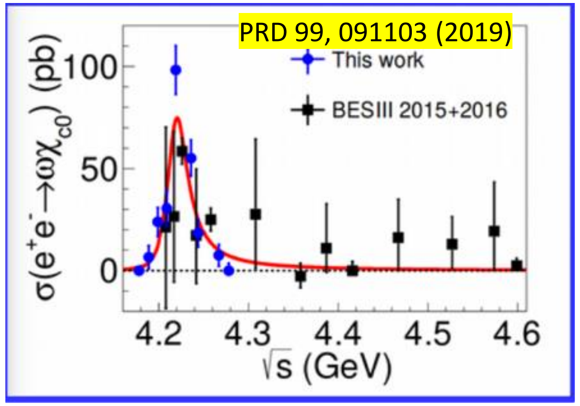
BESIII: $\sigma^B = 62.9 \pm 1.9 \pm 3.7$ pb

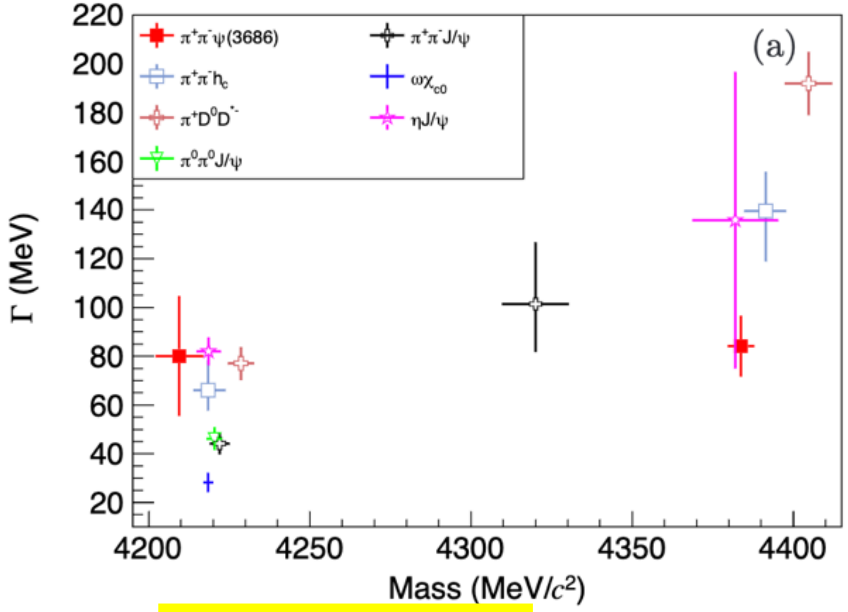
PRL 110, 252001 (2013)

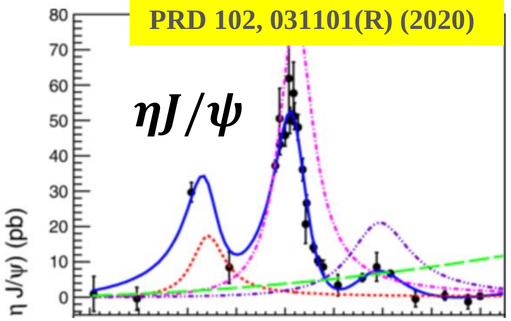
Y(4260) ➔ Y(4220) and new Y's

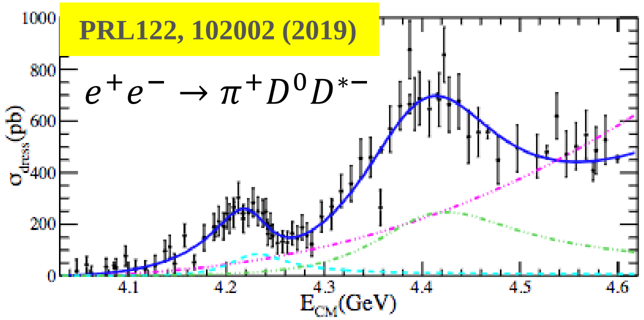


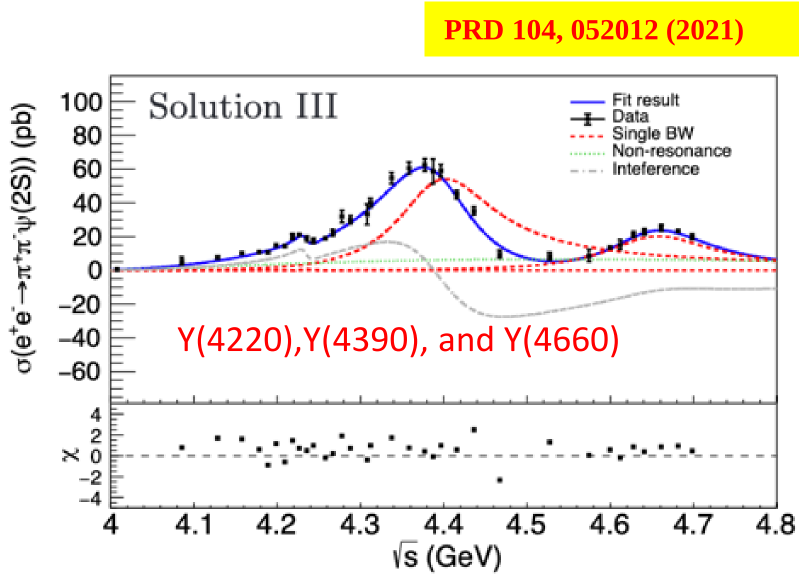


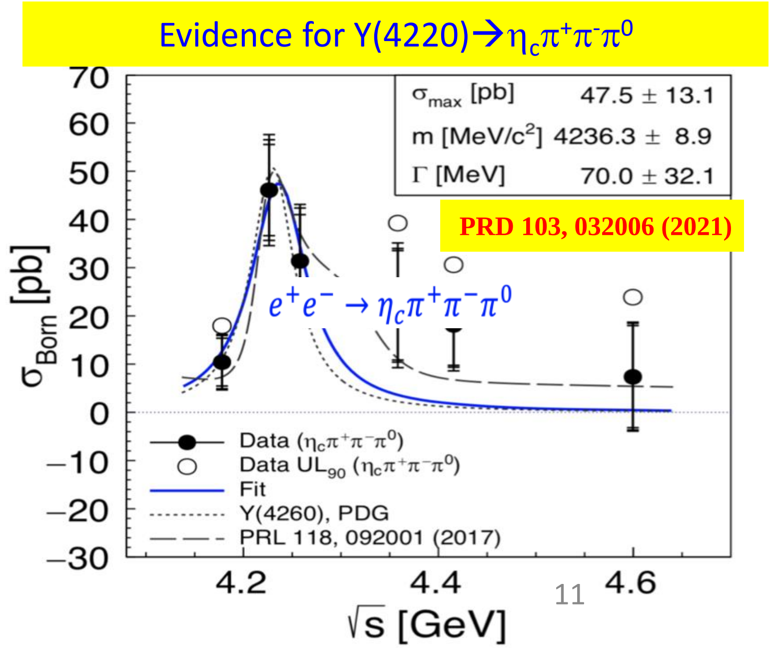








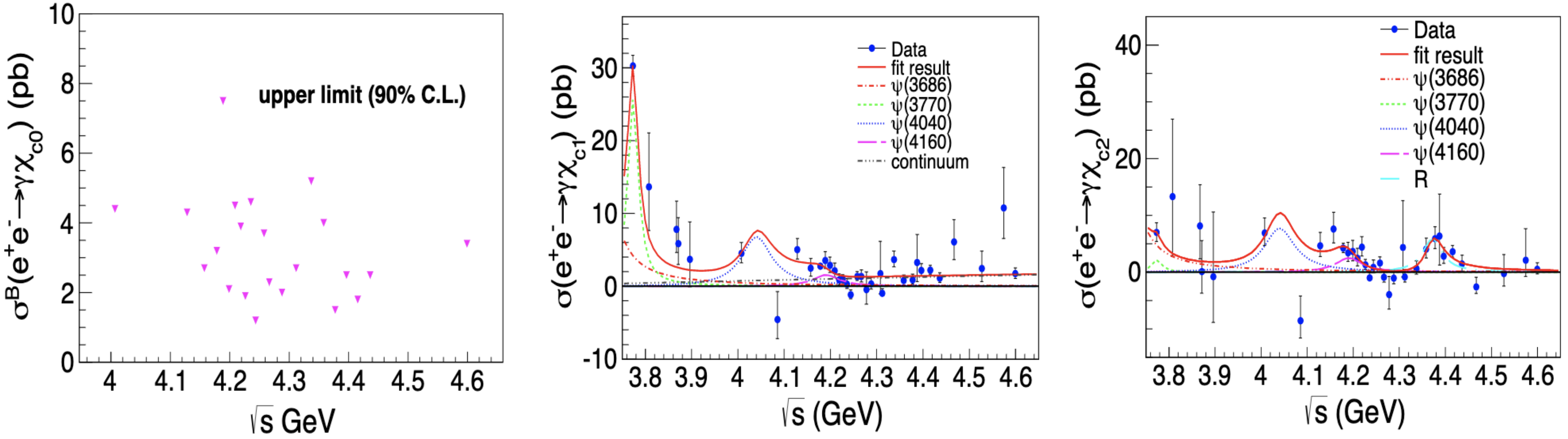




$e^+e^- \to \gamma\chi_{cJ}$ at $\sqrt{s}$=3.8-4.6 GeV

- **No signals for $e^+e^- \to \gamma\chi_{c0}$**
- **Observations of $e^+e^- \to \gamma\chi_{c1,2}$**

Phys.Rev.D 104 (2021) , 092001



- $\gamma\chi_{c1}$: Well describe with conventional charmonium states
- $\gamma\chi_{c2}$: Along with conventional ones, an additional Y state is needed

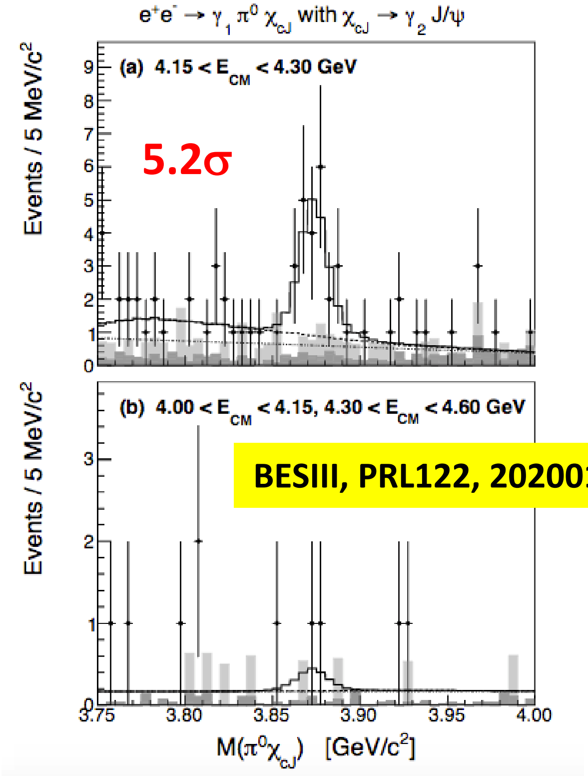
$$M = 4371.7 \pm 7.5 \pm 1.8\ \text{MeV}/c^2, \quad \Gamma = 51.1 \pm 17.6 \pm 1.9\ \text{MeV}$$

✓ statistical significance of 5.8 σ

✓ consistent with the Y(4360)/Y(4390)

More X(3872) decay information

- Observation of X(3872) →$\pi^0\chi_{c1}$



BESIII, PRL122, 202001 (2019)

- Observation of X(3872) → ωJ/ψ

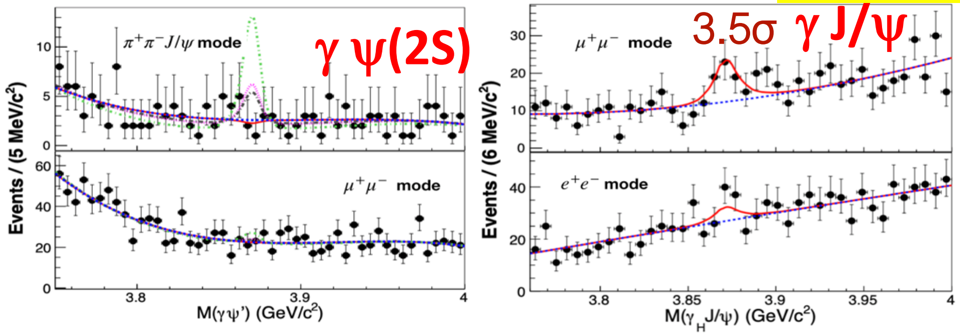
BESIII, PRL 122, 232002 (2019)

- Observation of X(3872) →$D^0\bar{D}^{*0}$

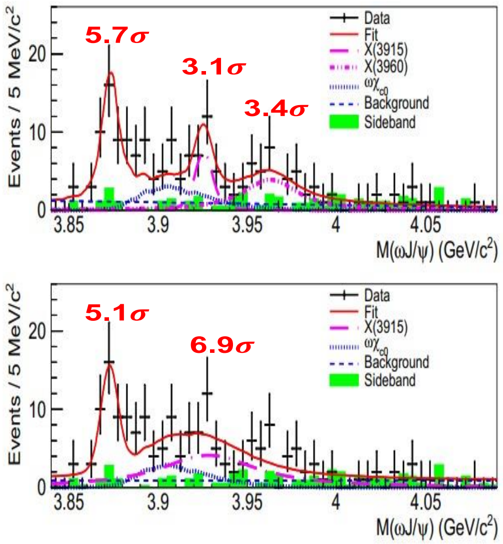
BESIII, PRL 124, 242001 (2020)

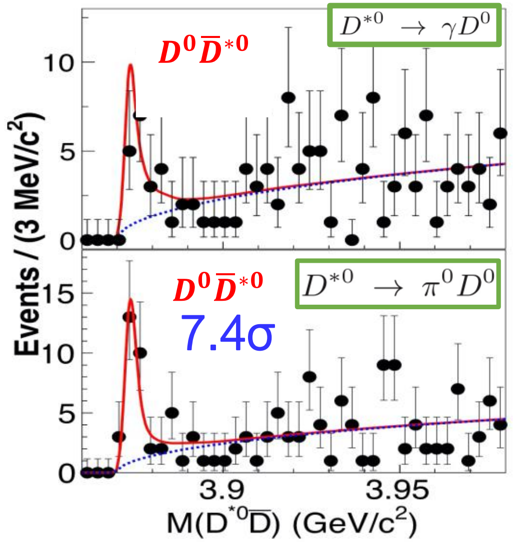
- Transition of $X(3872)$ → γJ/ψ, γψ(2S)

BESIII, PRL 124, 242001 (2020)

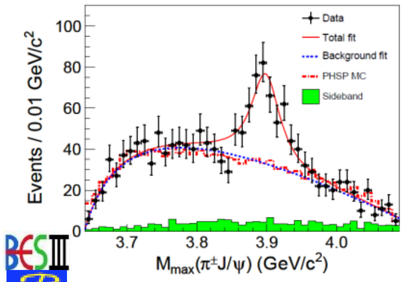


R=$\frac{\text{BF}(X(3872)\to\gamma\psi(2S))}{\text{BF}(X(3872)\to\gamma J/\psi)}$<0.59 at 90% C.L. , agrees with Belle(<2.1), while challenges Babar(3.4±1.1) and LHCb results (2.46± 0.70)

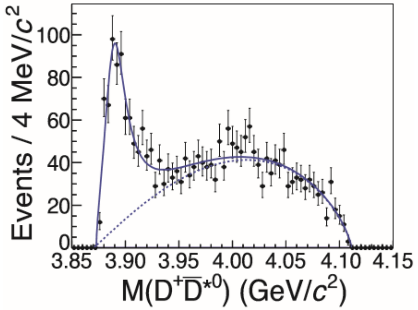




The Zc Family at BESIII

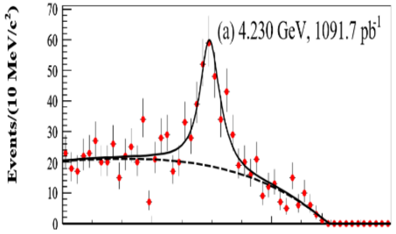


$e^+e^- \to \pi^+ \pi^- J/\psi$

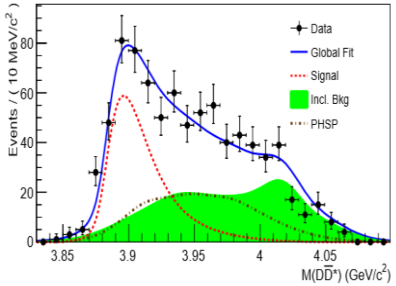


$e^+e^- \to \pi^+ (D\bar{D}^*)^-$

$Z_c(3900)^\pm$

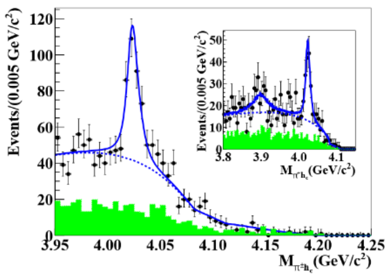


$e^+e^- \to \pi^0 \pi^0 J/\psi$

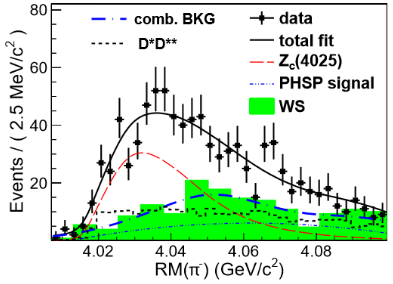


$e^+e^- \to \pi^0 (D\bar{D}^*)^0$

$Z_c(3900)^0$

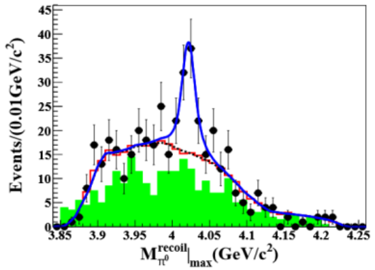


$e^+e^- \to \pi^+ \pi^- h_c$

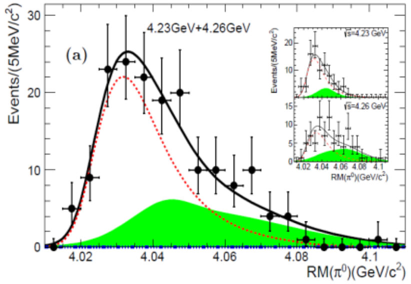


$e^+e^- \to \pi^+ (D^*\bar{D}^*)^-$

$Z_c(4020)^\pm$

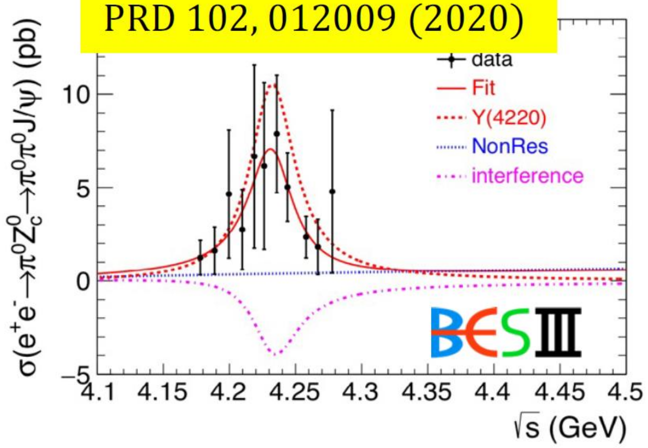


$e^+e^- \to \pi^0 \pi^0 h_c$

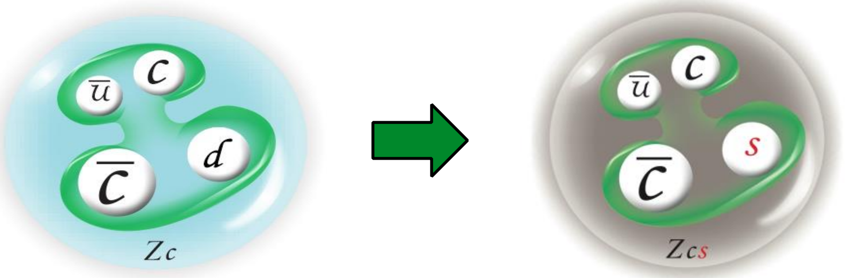


$e^+e^- \to \pi^0 (D^*\bar{D}^*)^0$

$Z_c(4020)^0$



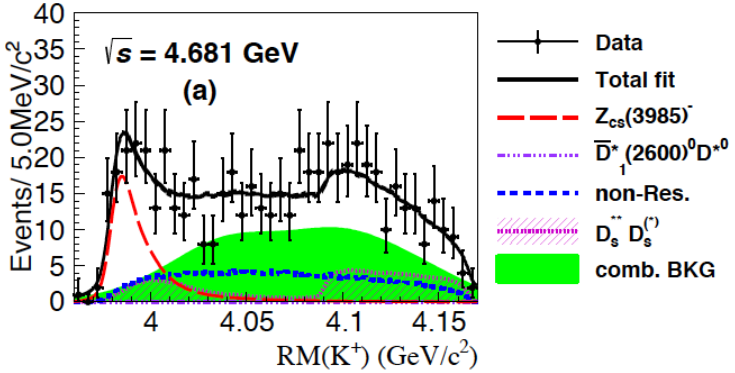
Which is the nature of these states?
If exists, there should be SU(3) counter-part
Zcs state with strangeness

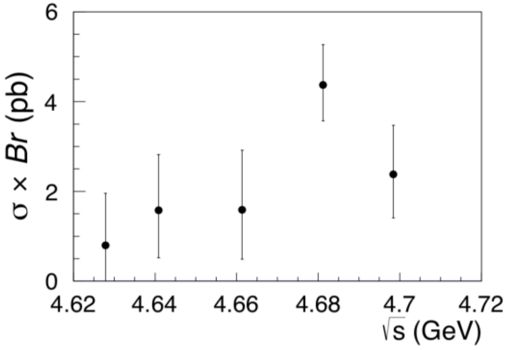


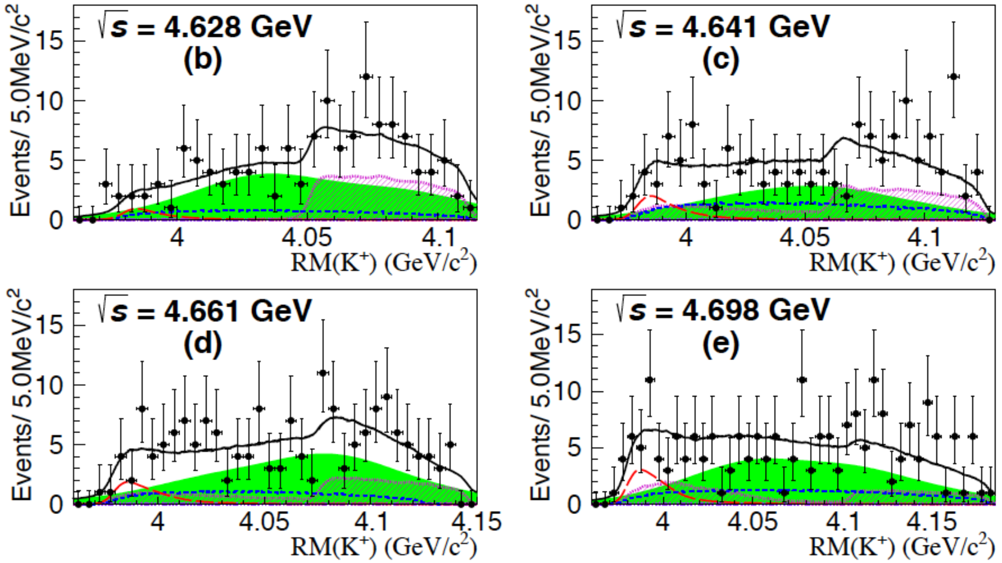
Observation of the $Z_{cs}(3985)^{\pm}$

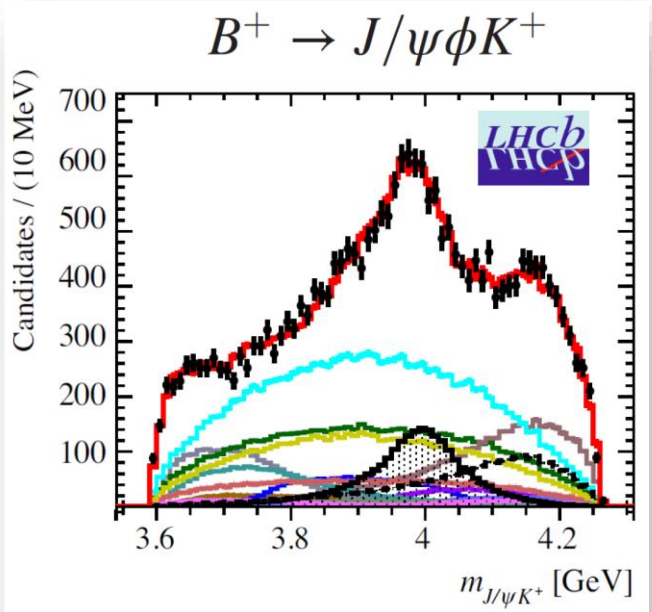
$e^+e^- \rightarrow K^+(D_s^- D^{*0} + D_s^{*-} D^0)$ **PRL126, 102001 (2021)**

- **Simultaneous fit to the five energy points**









PRL 127, 082001 (2021)

State	Signif.	JP	Mass (MeV)	Width (MeV)
$Z_{cs}(3985)$	5.3σ	??	$3982.5^{+1.8}_{-2.6} \pm 2.1$	$12.8^{+5.3}_{-4.4} \pm 3.0$
$Z_{cs}(4000)$	15σ	1+	$4003 \pm 6^{+4}_{-14}$	131±15±26
$Z_{cs}(4220)$	5.9σ	1+	$4216 \pm 24^{+43}_{-30}$	$233 \pm 52^{+97}_{-73}$

High statistics analysis of $e^+e^- \rightarrow K^+K^-J/\psi$ is desirable

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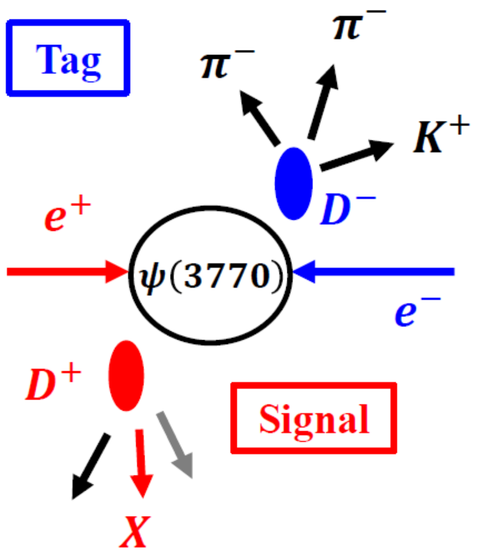


- **Single tag (ST):**

fully reconstruct one D^-

$$\Delta E = E_{D^-} - E_{\mathrm{beam}}$$

$$M_{\mathrm{BC}} = \sqrt{E^2_{\mathrm{beam}} - |\vec{p}_{D^-}|^2}$$

□ **Double tag (DT):**

in the recoil ST $D^-_{(s)}$,

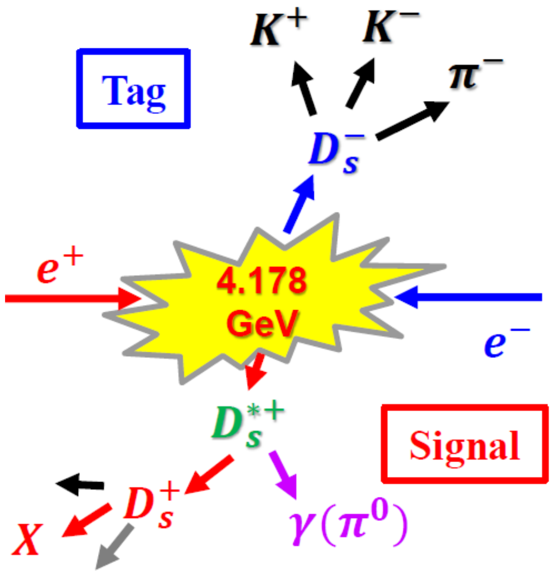
analyze the signal $D^+_{(s)}$

$$\mathrm{MM}^2 = E^2_{\mathrm{miss}} - |\vec{p}_{\mathrm{miss}}|^2$$

$$E_{\mathrm{miss}} = E_{\mathrm{cm}} - \sqrt{\left|\vec{p}_{D^-_{(s)}}\right|^2 + M^2_{D_{(s)}}} - E_X$$

$$\vec{p}_{\mathrm{miss}} = -\vec{p}_{D^-_{(s)}} - \vec{p}_X$$

$$U_{\mathrm{miss}} = E_{\mathrm{miss}} - |\vec{p}_{\mathrm{miss}}|$$



- **Single tag (ST):**

fully reconstruct one D_s^-

$$M_{\mathrm{rec}} = \sqrt{\left(E_{\mathrm{cm}} - \sqrt{|\vec{p}_{D_s^-}|^2 + m^2_{D_s^-}}\right)^2 - |-\vec{p}_{D_s^-}|^2}$$

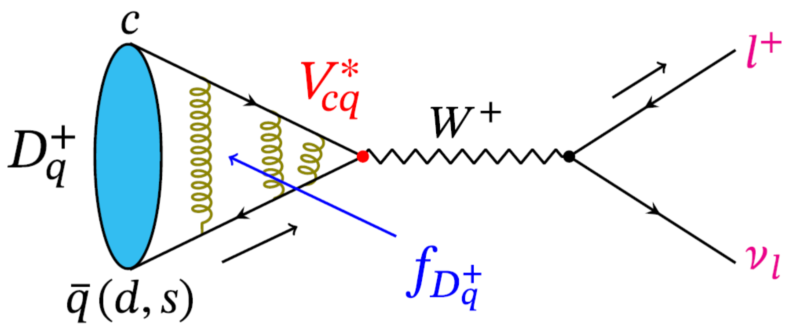
ST yield: $N^i_{\mathrm{ST}} = 2 \times N_{D\bar{D}} \times B^i_{\mathrm{ST}} \times \varepsilon^i_{\mathrm{ST}}$

DT yield: $N^i_{\mathrm{DT}} = 2 \times N_{D\bar{D}} \times B^i_{\mathrm{ST}} \times B_{\mathrm{sig}} \times \varepsilon^i_{\mathrm{ST\ vs.sig}}$

Average eff.: $\bar{\varepsilon}_{\mathrm{sig}} = \sum_{i=1}^{N} (N^i_{\mathrm{ST}} \times \varepsilon^i_{\mathrm{ST\ vs.sig}} / \varepsilon^i_{\mathrm{ST}}) / \sum_{i=1}^{N} N^i_{\mathrm{ST}}$

Absolute Br. $B_{\mathrm{sig}} = \dfrac{N^{\mathrm{tot}}_{\mathrm{DT}}}{N^{\mathrm{tot}}_{\mathrm{ST}} \times \bar{\varepsilon}_{\mathrm{sig}}}$

Pure leptonic decay



$$\Gamma\left(D_{(s)}^+ \to l^+\nu\right) = \frac{G_F^2\, f_{D_{(s)}^+}^2}{8\pi} \left|V_{cd(s)}\right|^2 m_l^2\, m_{D_{(s)}^+} \left(1 - \frac{m_l^2}{m_{D_{(s)}^+}^2}\right)^2$$

- Decay constant $f_{D_{(s)}^+}$

Exp. decay rate + $\left|V_{cs(d)}\right|^{CKMfitter}$ → calibrate LQCD @charm & extrapolate to Beauty

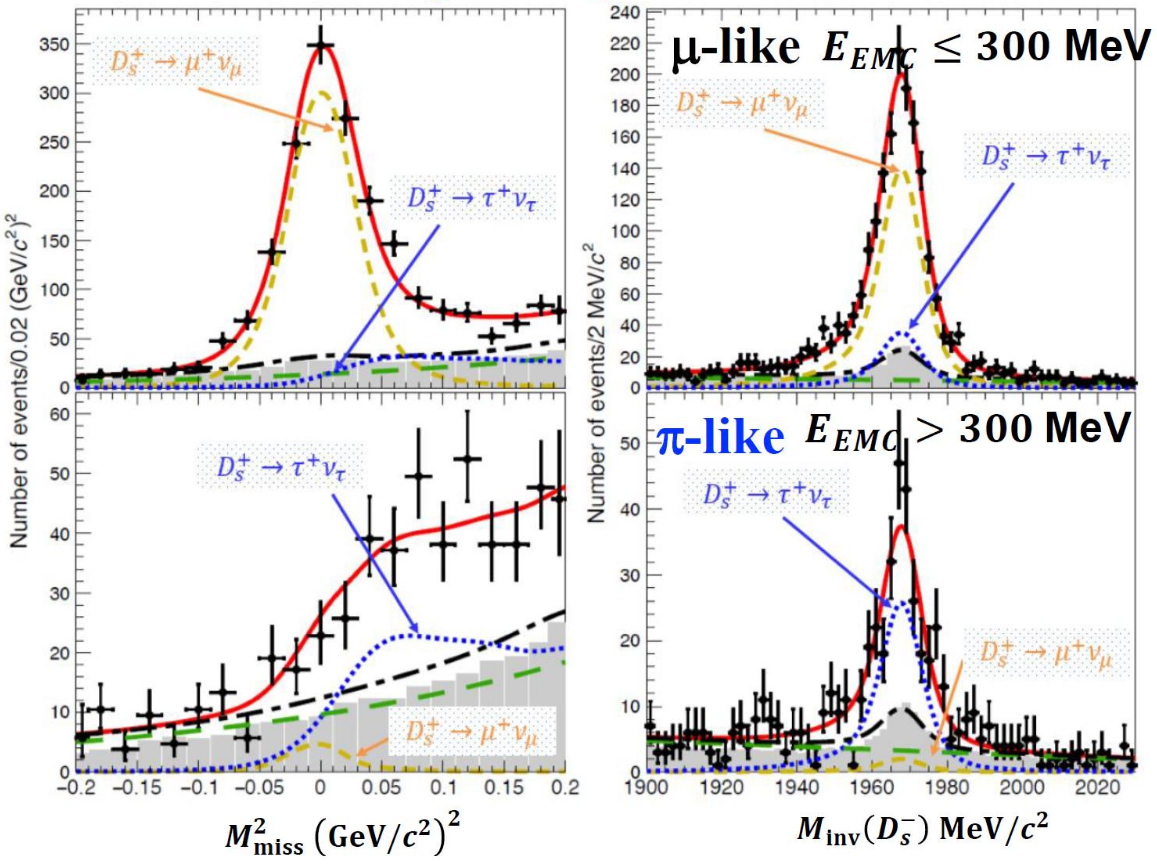
- CKM matrix element $\left|V_{cs(d)}\right|$

Exp. decay rate + LQCD → CKM matrix elements

$D_s^+ \to \mu^+\nu_\mu$ and $D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to \pi^+\bar{\nu}_\tau$

- **An unbinned simultaneous maximum likelihood fit to two-dimensional distributions**

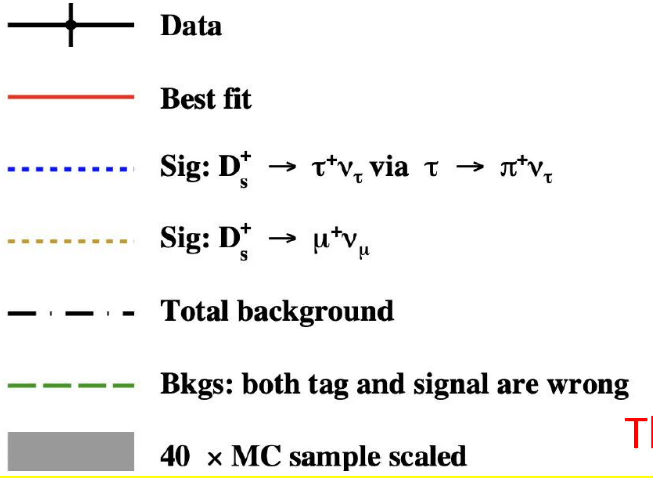
Only show @ 4.178 GeV



For all data samples

$$N^{\rm signal}_{D_s^+\to\mu^+\nu_\mu} = 2198 \pm 55$$

$$N^{\rm signal}_{D_s^+\to\tau^+\nu_\tau} = 946^{+46}_{-45}$$



The most precise result to date

$$B(D_s^+ \to \mu^+\nu_\mu) = (5.35 \pm 0.13_{\rm stat.} \pm 0.16_{\rm syst.}) \times 10^{-3}$$

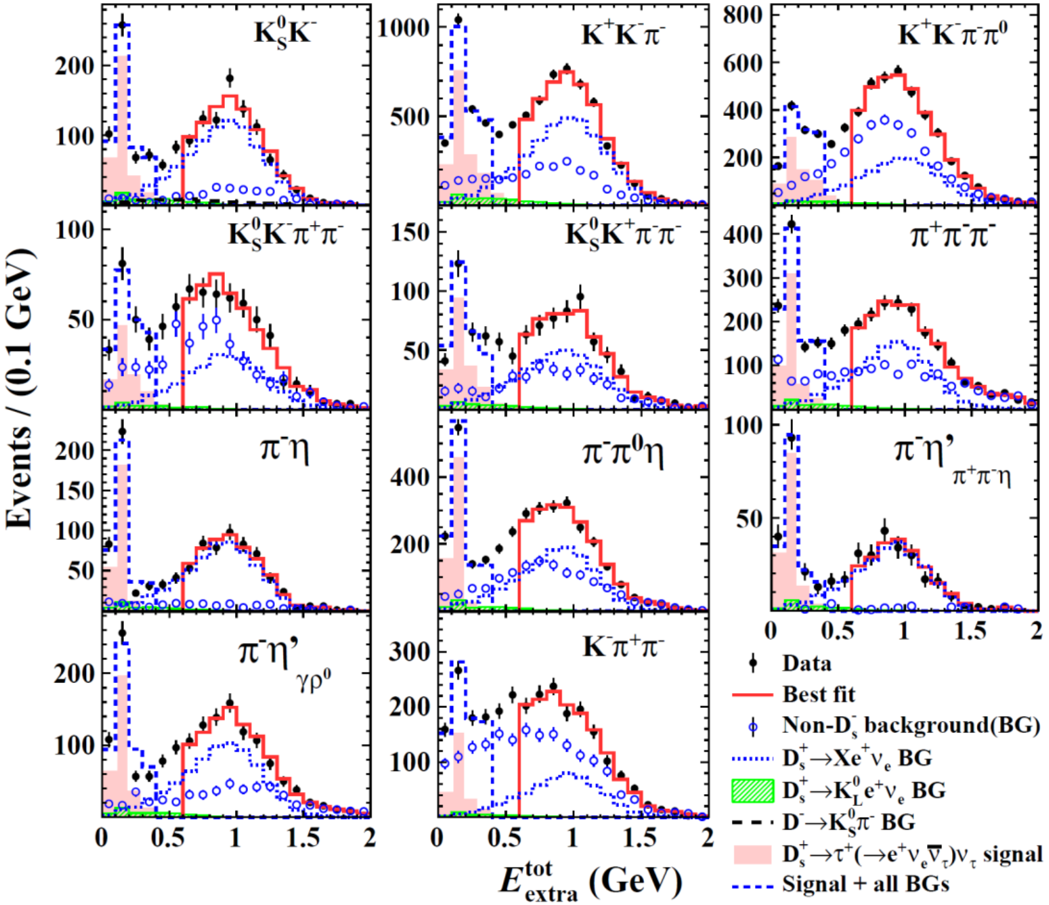
$$B(D_s^+ \to \tau^+\nu_\tau) = (5.21 \pm 0.25_{\rm stat.} \pm 0.17_{\rm syst.}) \times 10^{-2}$$

Phys.Rev.D 104 (2021), 052009

$D_s^+ \to \tau^+\nu_\tau$ via $\tau^+ \to e^+\nu_e\bar{\nu}_\tau$

- ✓ $E_{\rm extra}^{\rm tot}$: **the total energy of the good EMC showers, excluding those associated with the ST D_s^- candidates and those within 5°of the initial direction of the positron.**

- ✓ **DT yield $N_{\rm DT} = N_{\rm DT}^{\rm tot} - N_{\rm DT}^{{\rm non}-D_s^-} - N_{\rm DT}^{K_L^0 e^+\nu_e} - N_{\rm DT}^{Xe^+\nu_e}$** **(in signal $E_{\rm extra}^{\rm tot} < 0.4$ GeV)**



Phys. Rev. Lett. 127 (2021) 171801

The most precise result to date

BESIII results		
Mode	$\mathcal{B}(D_s^+ \to \tau^+\nu_\tau)$	$\mathcal{B}(D_s^+ \to \mu^+\nu_\mu)$
$\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$	$(5.29 \pm 0.25 \pm 0.20)\%$	-
$\tau^+ \to \pi^+\bar{\nu}_\tau$	$(5.21 \pm 0.25 \pm 0.17)\%$	$(0.535 \pm 0.013 \pm 0.016)\%$
$\tau^+ \to e^+\nu_e\bar{\nu}_\tau$	$(5.27 \pm 0.10 \pm 0.12)\%$	-
Average	$(5.26 \pm 0.09 \pm 0.09)\%$	$(0.535 \pm 0.013 \pm 0.016)\%$

Combining our results with world averages

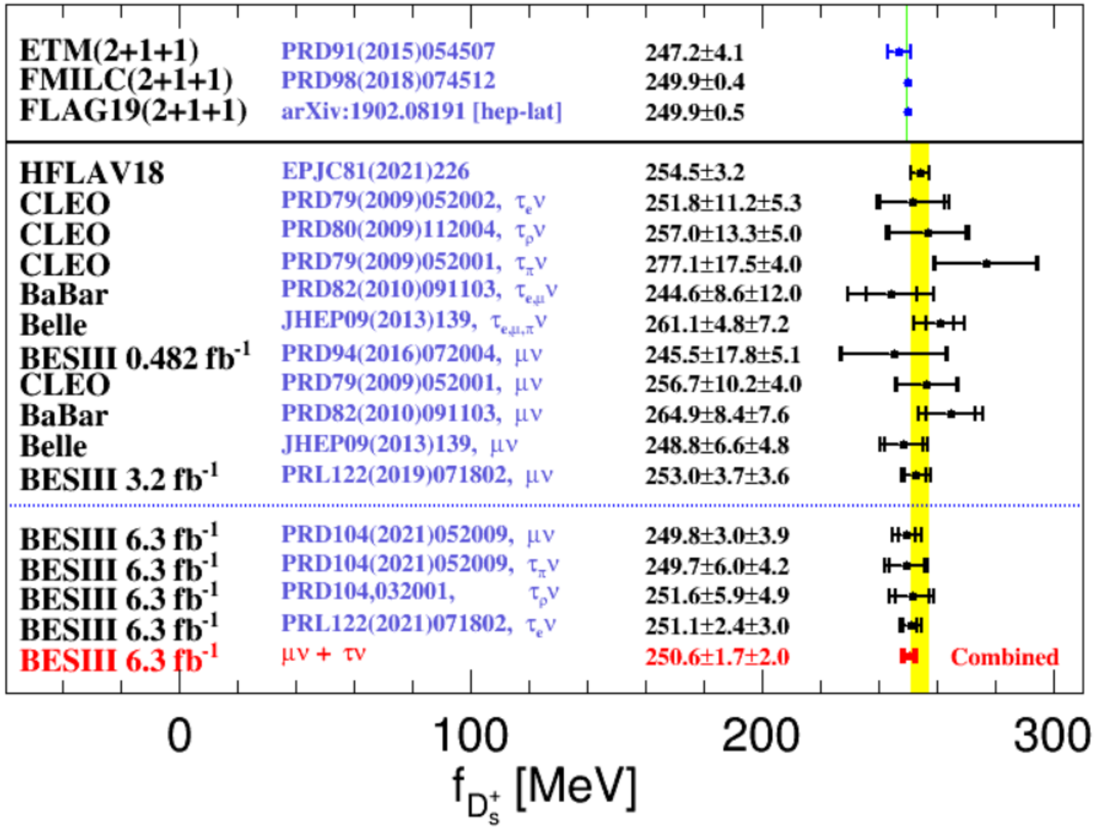
$$\mathcal{B}_{D_s^+\to\tau^+\nu_\tau}/\mathcal{B}_{D_s^+\to\mu^+\nu_\mu} = 9.72 \pm 0.37$$

SM prediction 9.75 ± 0.01

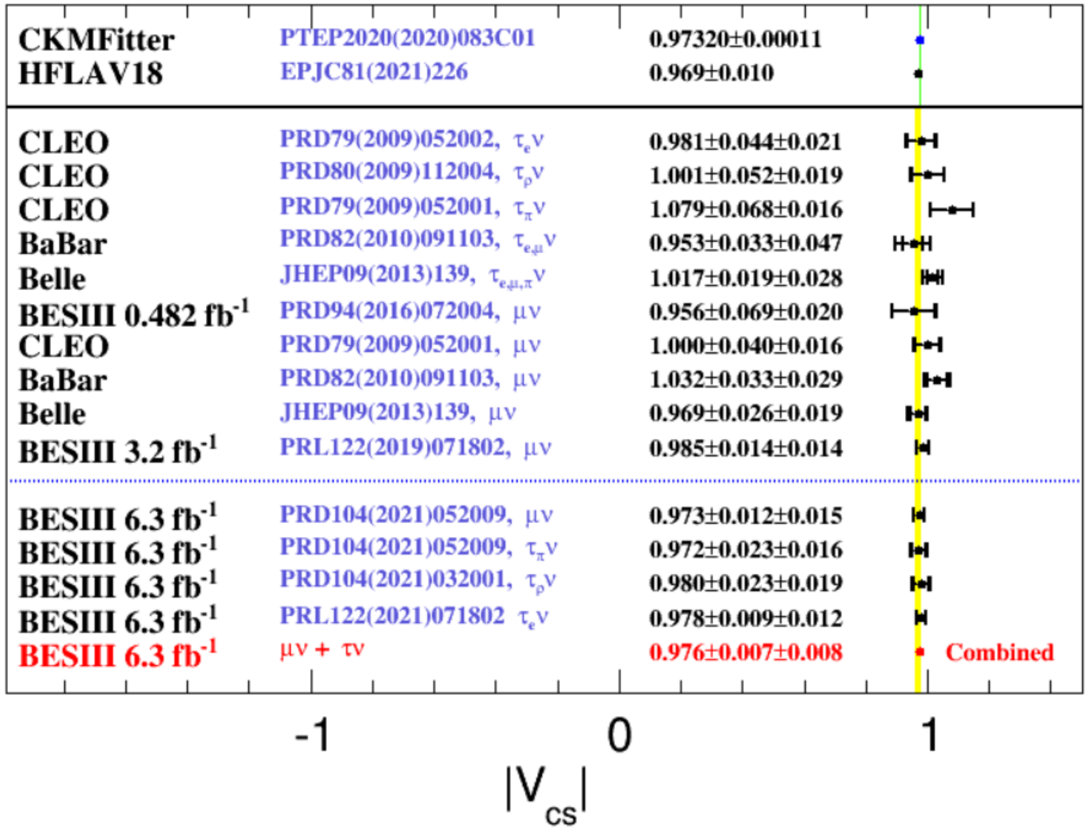
No LFU violation is found with the current precision

$$f_{D_s^+}|V_{cs}| = (244.4 \pm 2.3 \pm 2.9)MeV$$

Input $|V_{cs}| = 0.97320 \pm 0.00011$ from CKM global fit

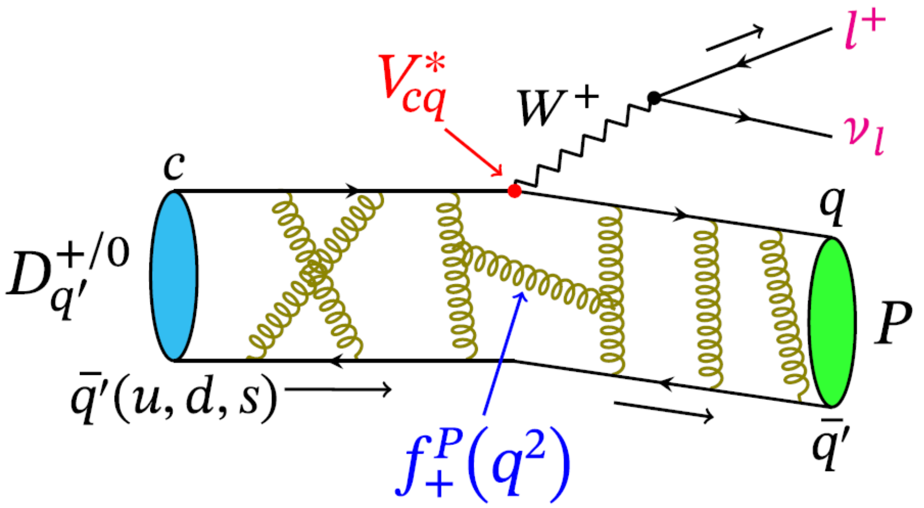


Input $f_{D_s^+} = 249.9 \pm 0.5$ from LQCD calculations (FLAVG19)



Most precise measurement

Semi-leptonic decay



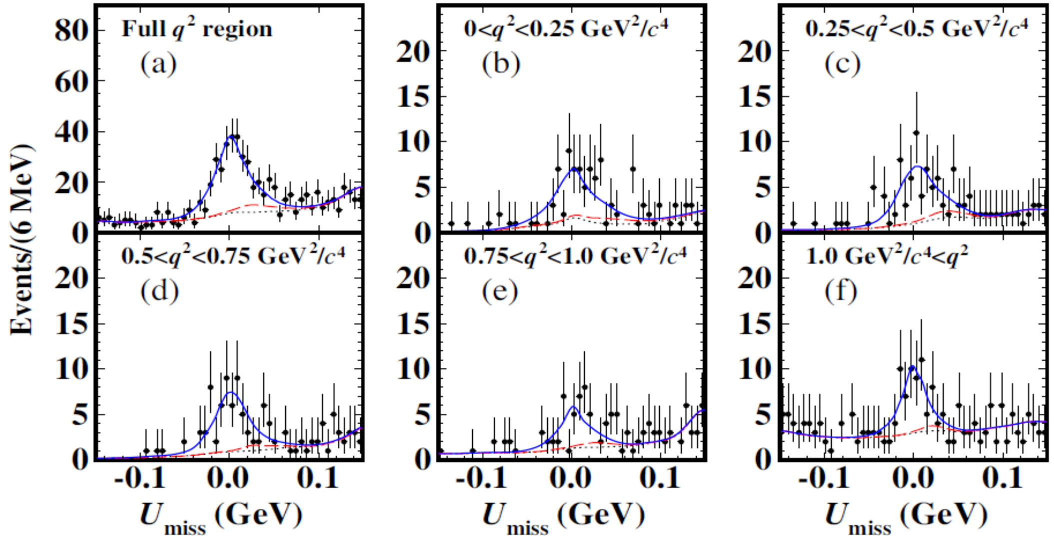
$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2 p^3}{24\pi^3}|f_+(q^2)|^2|V_{cd(s)}|^2 \; (X = 1 \; for \; K^-, \pi^-, \bar{K}^0, \eta^{(\prime)}; X = \frac{1}{2} \; for \; \pi^0)$$

- Analyze exp. partial decay rates → q^2 dependence of $f_+^{K(\pi)}(q^2)$, extract $f_+^{K(\pi)}(0)$ with $|V_{cs(d)}|^{CKMfitter}$ as input ---- calibrate QCD
- Exp. + LQCD calculation of $f_+^K(0)$ and $f_+^{\pi}(0)$ → $V_{cs(d)}$ ---- constrain CKM

First observation of $D^+ \to \eta\mu\nu_\mu$

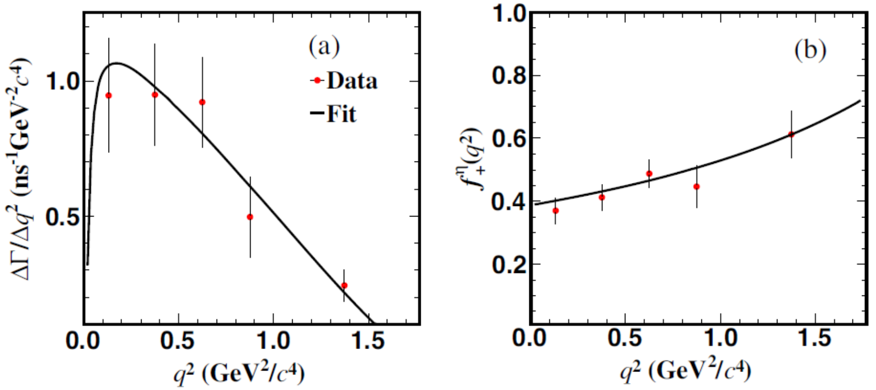
$2.93\mathrm{f}b^{-1} @ E_{cm} = 3.773\mathrm{GeV}$

$e^+e^- \to \psi(3770) \to D\bar{D}$



No. of single tags: $(1522.5\pm2.1)\times10^3$

No. of double tags: 234 ± 22



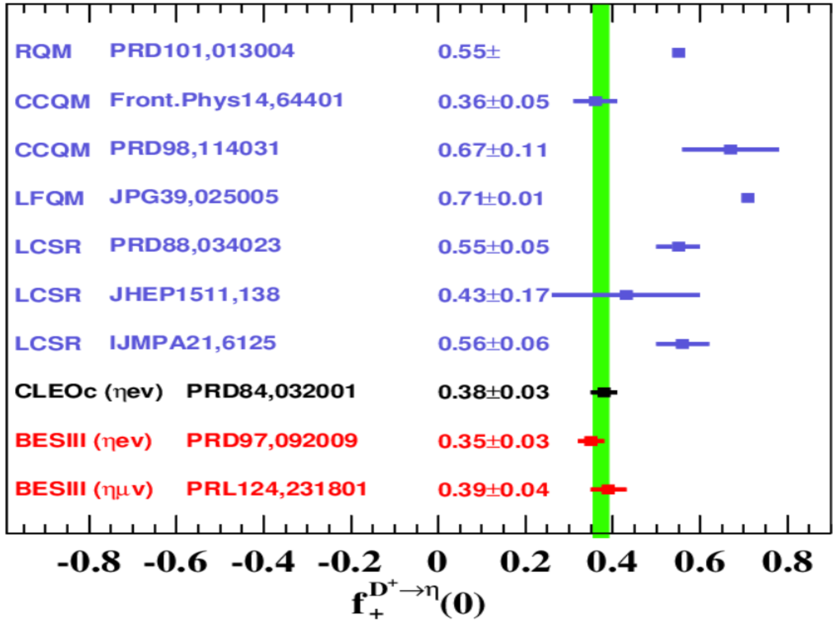
BESIII: PRL 124, 231801 (2020)

$$B[D^+ \to \eta\mu^+ v] = (0.104 \pm 0.010 \pm 0.005)\%$$

$$R_{D\eta} = \frac{\Gamma[D^+ \to \eta\mu^+ v]}{\Gamma[D^+ \to \eta e^+ v]} = 0.91 \pm 0.13$$

(SM prediction: 0.93-0.96)

$$f_+^{D\to\eta}(0)|V_{cd}| = 0.087(08)(02)$$

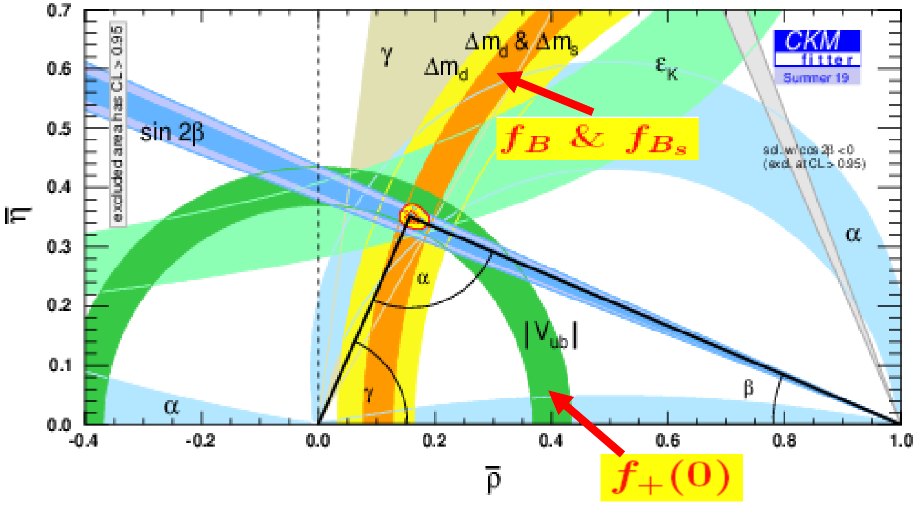


BESIII data @3770 MeV (2.93 fb^{-1} ➔ 20 fb^{-1})

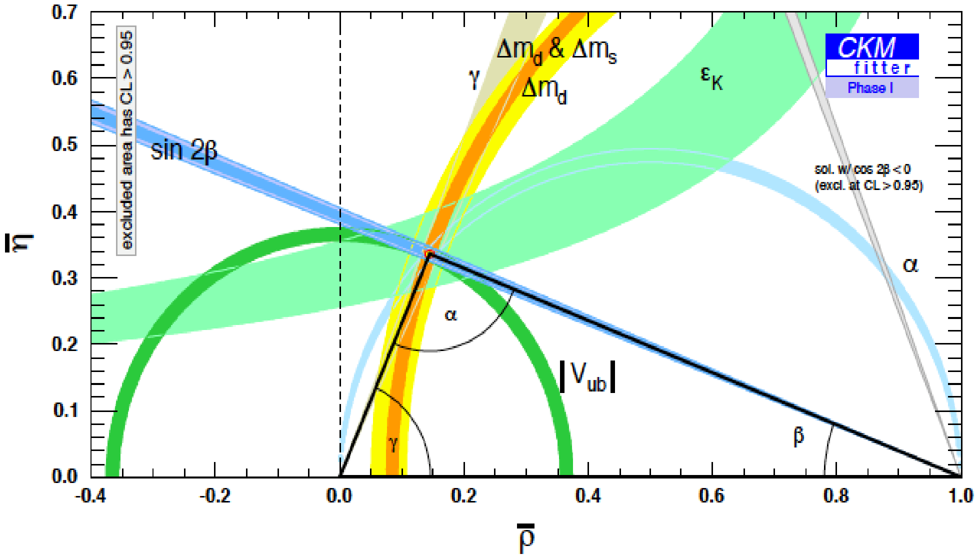
$\psi(3770)$➔$D^0\overline{D^0}$ quantum correlation➔strong phase parameters between D^0 and $\overline{D}^0$ decays

➔inputs to measurement of γ

Belle II (arXiv:1808.10567): 1.5^0 with 50 ab^{-1}
LHCb (arXiv:1808.08865v2): < 1°, 50 fb^{-1}, phase-1 upgrade (2030),
< 0.4°, 300 fb^{-1}, phase-2 upgrade (> 2035)



2019

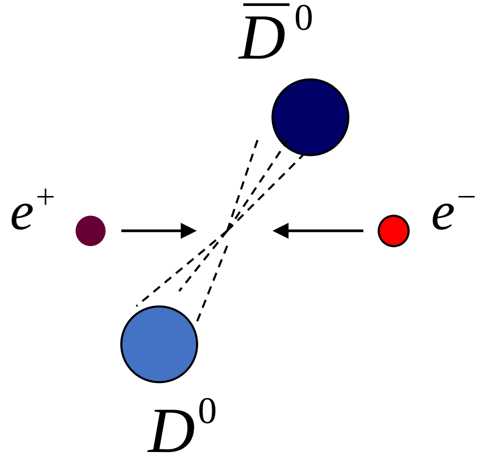


>year of 2030 (BESIII 20 fb^{-1} data as inputs)

BESIII White Paper, Chinese Phys. C 44 (2020) 040001

The correlated state

For a physical process producing $D^0\,\bar{D}^0$ such as



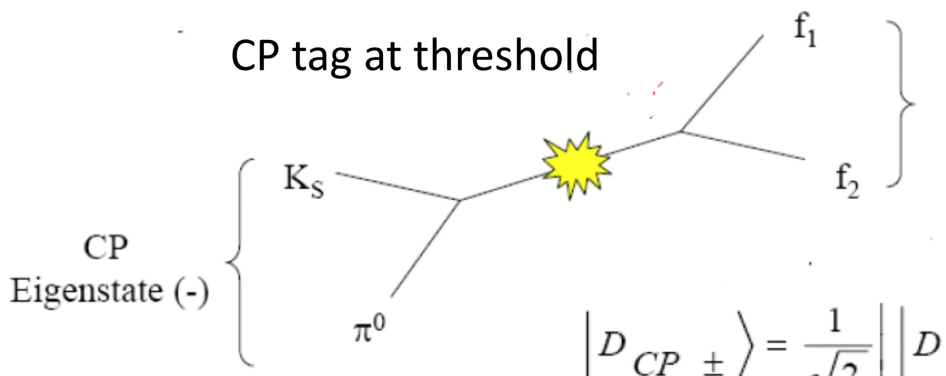
$$e^+e^- \rightarrow \psi'' \rightarrow D^0\bar{D}^0$$

The $D^0\,\bar{D}^0$ pair will be a quantum-correlated state

For a correlated state with $C = -$

$$\hat{C}\left|D^0\right\rangle = \left|\bar{D}^0\right\rangle$$
$$\hat{C}\left|\bar{D}^0\right\rangle = \left|D^0\right\rangle$$

$$\psi_- = \frac{1}{\sqrt{2}}\left(\left|D^0\right\rangle\left|\bar{D}^0\right\rangle - \left|\bar{D}^0\right\rangle\left|D^0\right\rangle\right)$$



$$\frac{\left\langle K^-\pi^+ \middle| \bar{D}^0 \right\rangle^{DCS}}{\left\langle K^-\pi^+ \middle| D^0 \right\rangle^{CF}} \equiv -r_{K\pi}e^{-i\delta_{K\pi}}$$

$$\left|D_{CP\pm}\right\rangle = \frac{1}{\sqrt{2}}\left[\left|D^0\right\rangle \pm \left|\bar{D}^0\right\rangle\right]$$

$$\sqrt{2}\,A\left(D_{CP\pm} \rightarrow K^-\pi^+\right) = A\left(D^0 \rightarrow K^-\pi^+\right) \pm A\left(\bar{D}^0 \rightarrow K^-\pi^+\right)$$

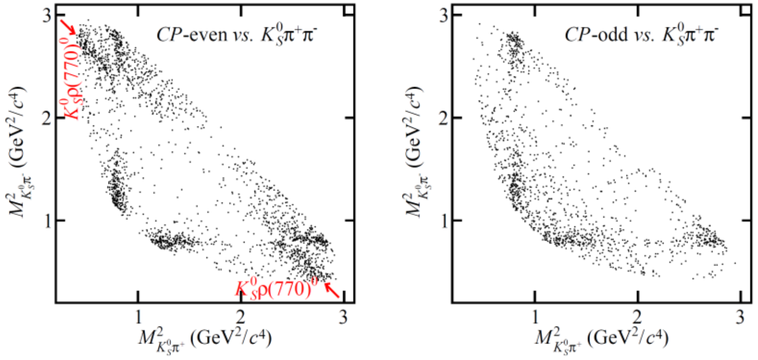
Strong phase measurements at BESIII

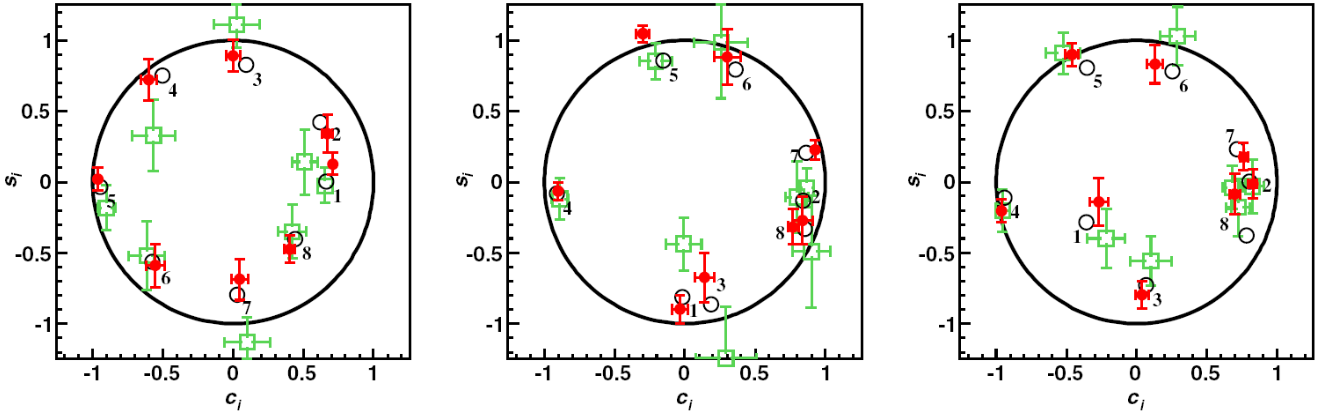
2.93 fb^{-1} @ $E_{cm} = 3.773$ GeV
$e^+e^- \to \psi(3770) \to D\bar{D}$

- $D \to K^0_{S/L}\pi^+\pi^-$

PRL 124 (2020)241802

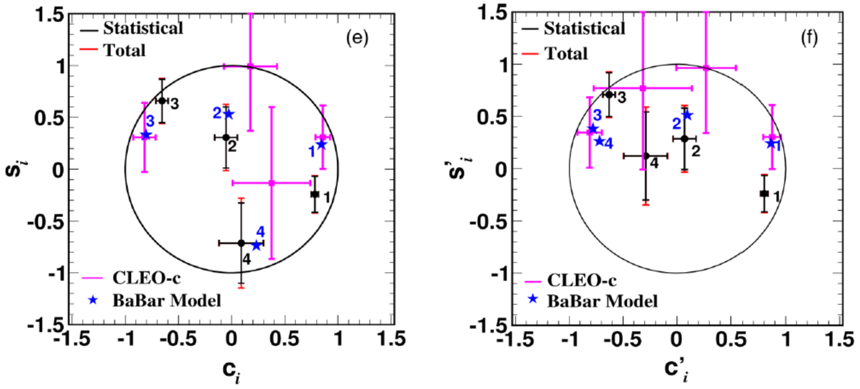
Constraint on γ measurement ~ 0.9^0





- $D \to K^0_{S/L}K^+K^-$

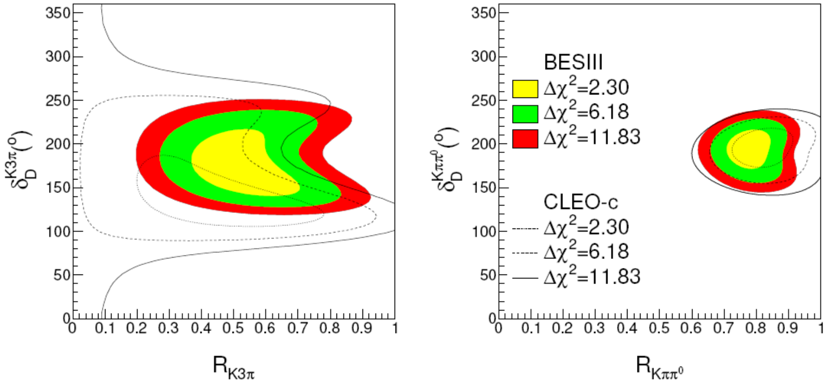
PRD102(2020)052008



Constraint on γ measurement ~ 1.3^0

- $D \to K^-\pi^+\pi^+\pi^-$ and $K^-\pi^+\pi^0$

JHEP 2021 (5) (2021) 164



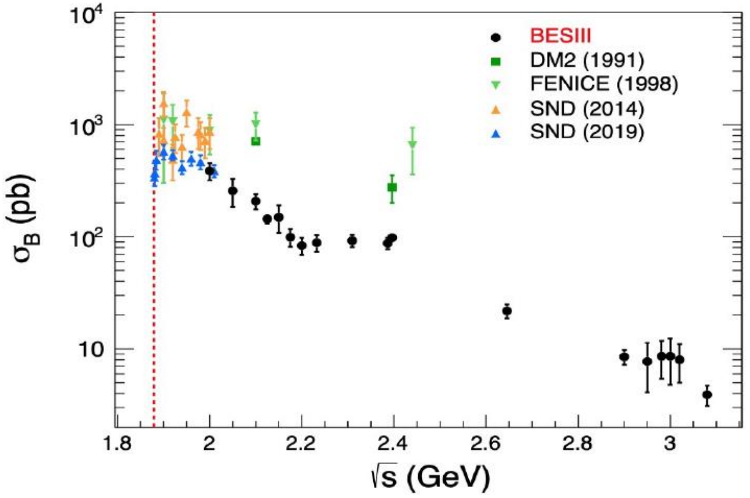
Constraint on γ measurement ~ 6^0

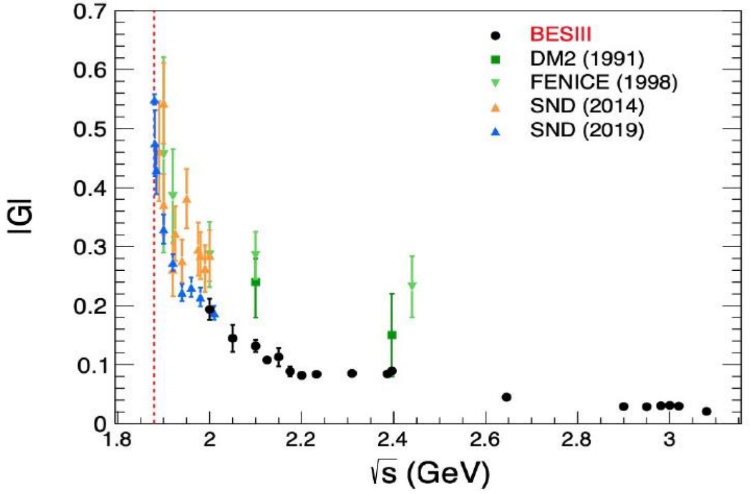
Selected topics

- Light hadrons: glueballs & more
- XYZ particles: Y(4260), X(3872), Zcs(3985)
- Charm decays: CKM, decay constants, form factors, LFU, $\Delta\delta_D$
- Baryons: form factors & polarization

Oscillation Structure in neutron Form Factor

Nature Physics 17, 1200 (2021)

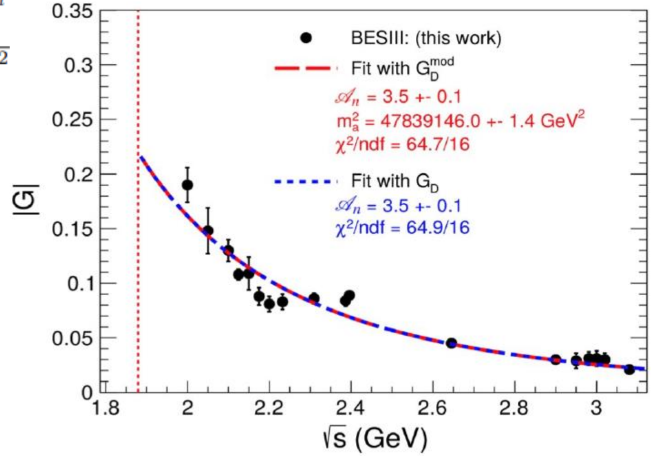


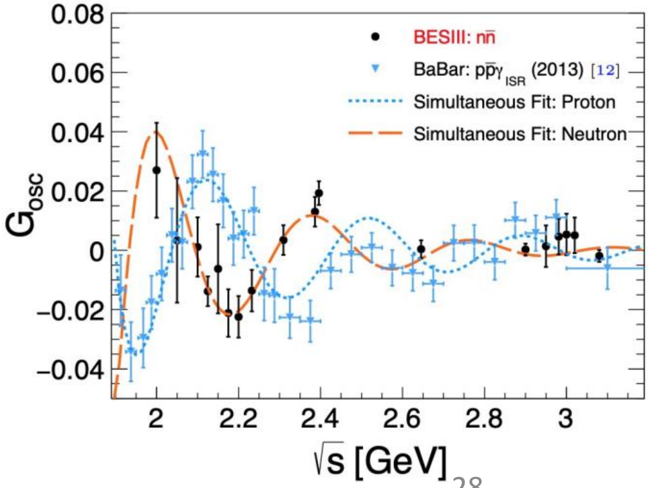


$$G_{osc}(q^2) = |G_n| - G_{D^*},$$

$$G_{D^*} = G_D \cdot \frac{1}{1 + \frac{q^2}{m_a^2}},$$

$$G_D = \frac{\mathcal{A}_n}{\left(1 - \frac{q^2}{0.71(\mathrm{GeV}^2)}\right)^2}$$



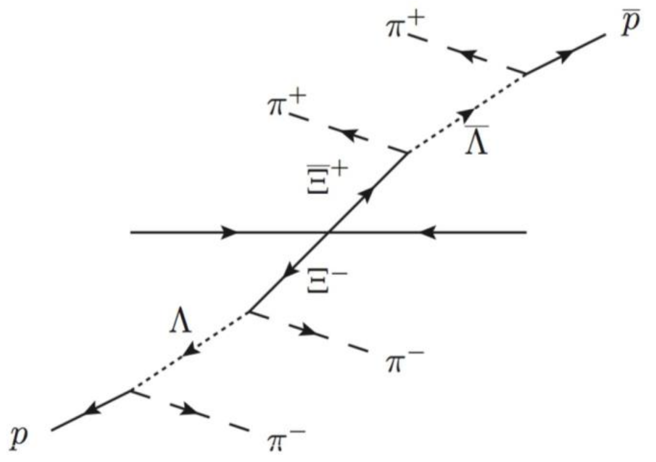


- a similar periodic structure of $|G_{eff}|$ as proton
- Simultaneous fit to $|G_{eff}|$ of neutron and proton yields a shared frequency $5.55 \pm 0.28\ GeV^{-1}$
- a large phase difference $\Delta b^{osc} = \left|b_{2p}^{osc} - b_{2n}^{osc}\right| = (125 \pm 12)^\circ$

$$F(p) = b_0^{\rm osc} e^{-b_1^{\rm osc} p} \cos(b_2^{\rm osc} p + b_3^{\rm osc})$$

Weak phase and CP-symmetry tests in sequential decays of entangled $\Xi^+\Xi^-$ pairs

arXiv:2105.11155



- First measurement of weak phase difference
- First direct measurement of Ξ decay parameters
- Independent measurement of Λ decay parameter
- Strong phase diff. consistent with zero

Parameter	This work	Previous result	
α_ψ	$0.586 \pm 0.012 \pm 0.010$	$0.58 \pm 0.04 \pm 0.08$	[39]
$\Delta\Phi$	$1.213 \pm 0.046 \pm 0.016$ rad	–	
α_Ξ	$-0.376 \pm 0.007 \pm 0.003$	-0.401 ± 0.010	[21]
ϕ_Ξ	$0.011 \pm 0.019 \pm 0.009$ rad	-0.037 ± 0.014 rad	[21]
$\overline{\alpha}_\Xi$	$0.371 \pm 0.007 \pm 0.002$	–	
$\overline{\phi}_\Xi$	$-0.021 \pm 0.019 \pm 0.007$ rad	–	
α_Λ	$0.757 \pm 0.011 \pm 0.008$	$0.750 \pm 0.009 \pm 0.004$	[14]
$\overline{\alpha}_\Lambda$	$-0.763 \pm 0.011 \pm 0.007$	$-0.758 \pm 0.010 \pm 0.007$	[14]
$\xi_p - \xi_s$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad	–	
$\delta_p - \delta_s$	$(-4.0 \pm 3.3 \pm 1.7) \times 10^{-2}$ rad	$(10.2 \pm 3.9) \times 10^{-2}$ rad	[17]
A^Ξ_{CP}	$(6.0 \pm 13.4 \pm 5.6) \times 10^{-3}$		
$\Delta\phi^\Xi_{CP}$	$(-4.8 \pm 13.7 \pm 2.9) \times 10^{-3}$ rad		
A^Λ_{CP}	$(-3.7 \pm 11.7 \pm 9.0) \times 10^{-3}$	$(-6 \pm 12 \pm 7) \times 10^{-3}$	[14]
$\langle\phi_\Xi\rangle$	$0.016 \pm 0.014 \pm 0.007$ rad		

Consistent with CP symmetry

Same precise as HyperCP with $O(10^3)$ smaller statistics

Planned future data set

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 most right column shows the number of required data taking days in current (T_C) or 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

to be complete in 2022-23

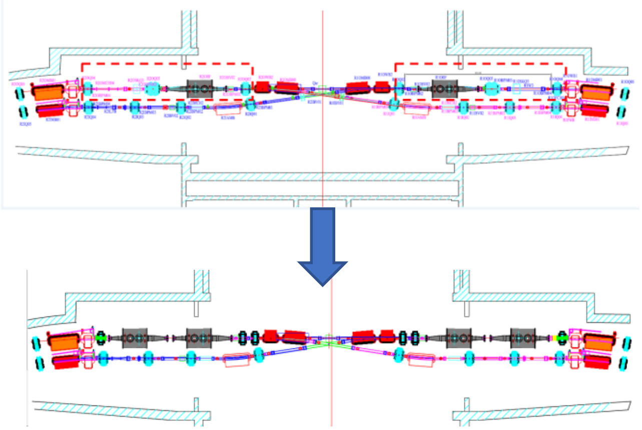
~55 fb^{-1}

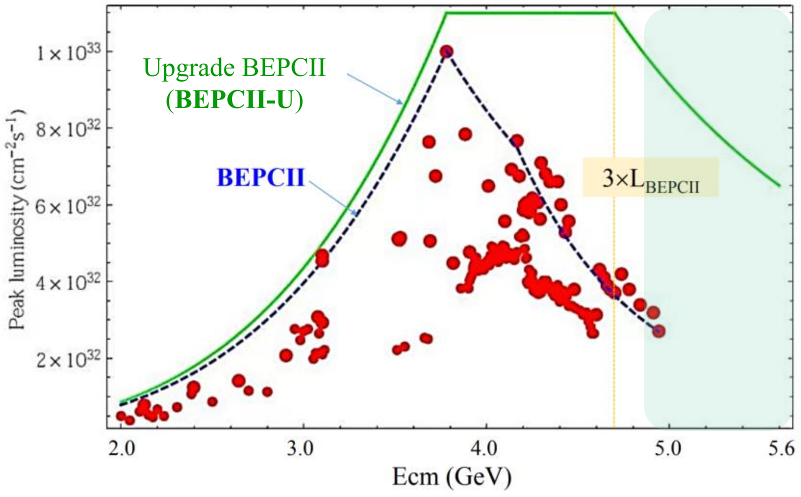
Proposal of the upgrade BEPCII

✓ An upgrade of BEPCII (**BEPCII-U**) has been approved in July 2021: **the optimized energy is 2.35 GeV with luminosity 3 times higher than current BEPCII and extend the maximum energy to 5.6 GeV**

- Add another cavity per beam to improve the RF power
- Change optics slightly, increase number of bunches
- Challenges: high beam intensities, backgrounds and aging effect in the detector
- Small risk: can continue running with better performance than BEPCII
- Timescale: 2.5 years construction + 0.5 year installation
- Installation: July – December 2024 and the upgraded machine ready in Jan. 2025

	BEPCII	BEPCII-U
Lum [$10^{32}cm^{-2}s^{-1}$]	3.5	11
β_y^* [cm]	1.5	1.35
Bunch Current [mA]	7.1	7.5
Bunch Num	56	120
SR Power [kW]	110	250
$\xi_{y,lum}$	0.029	0.033
Emittance [nmrad]	147	152
Coupling [%]	0.53	0.35
Bucket Height	0.0069	0.011
$\sigma_{z,0}$ [cm]	1.54	1.07
σ_z [cm]	1.69	1.22
RF Voltage [MV]	1.6	3.3





Summary

- Data with unprecedented statistical accuracy from BESIII provides great opportunities to hadron physics and flavor physics. Will continue to run for ~10 years
- BESIII is in good status, inner detector upgrade in progress
- High-lumi. fine scan between 3.8 GeV and 5.6 GeV is planned
  ➔ BEPCII-U: 3x upgrade on luminosity
- To obtain a complete picture, different experiments with complementary information are needed
- Synergies between experiment and theory are essential

Thank you for your attention