Searching for Flavor Changing Neutral Currents at BESIII

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(for BESIII Collaboration)

FCNC is suppressed in SM

PHYSICAL REVIEW D VOLUME 2, NUMBER 7 1 OCTOBER 1970

Weak Interactions with Lepton-Hadron Symmetry*

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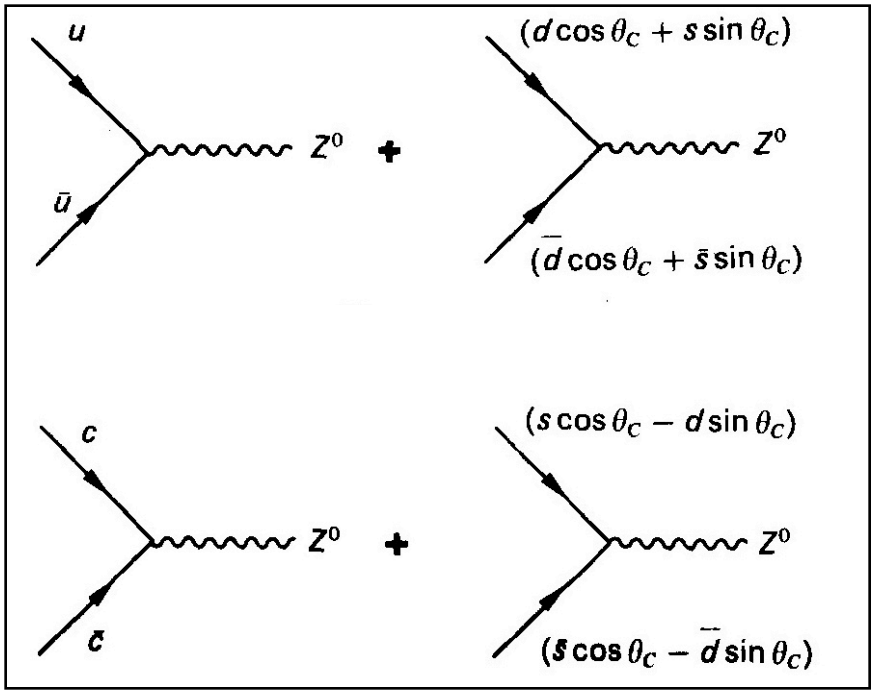
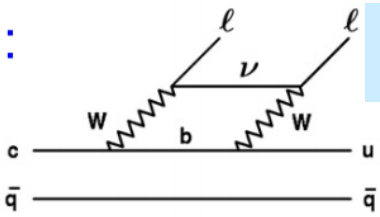
(Received 5 March 1970)

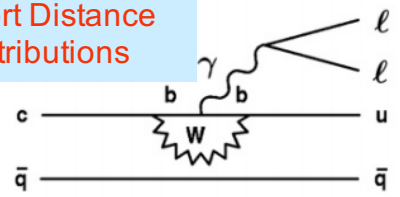


BESIII can probe c→ ull, esp c→ uee

Stronger diagram cancellation than down-types

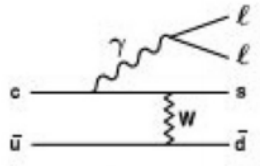


Short Distance contributions

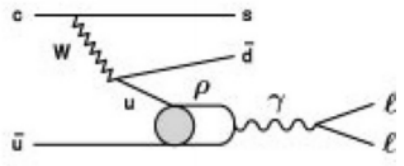


$$\mathcal{L}_{eff}^{SD} = \frac{G_F}{\sqrt{2}} V_{cb}^* V_{ub} \sum_{i=7,9,10} C_i Q_i,$$

Sensitive to new physics



(a)

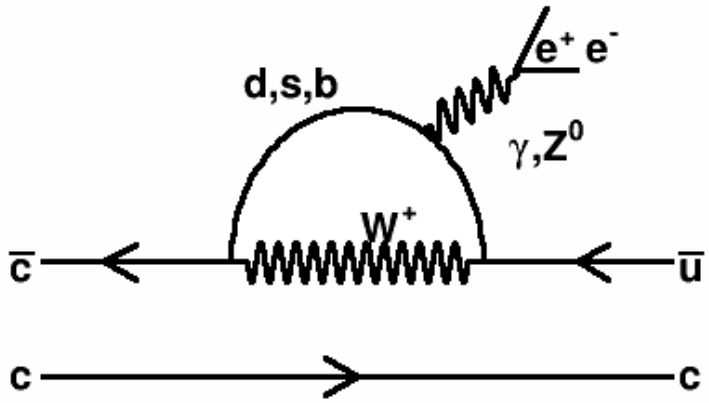


(b)

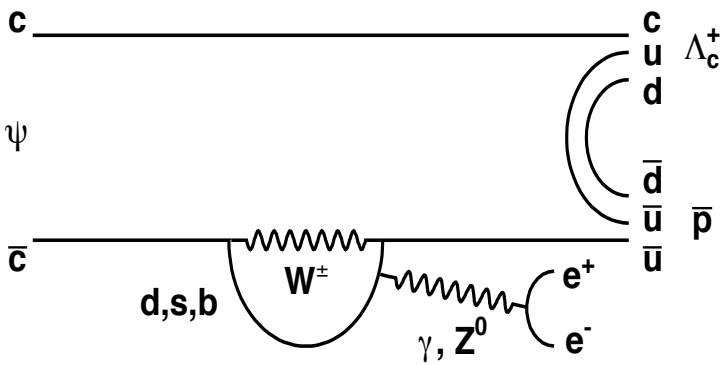
Long Distance contributions

D → hee

FCNC in charm decays



$J/\psi(\psi(3686)) \to D^0 e^+ e^-$



$\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^-$

Reported in this talk:

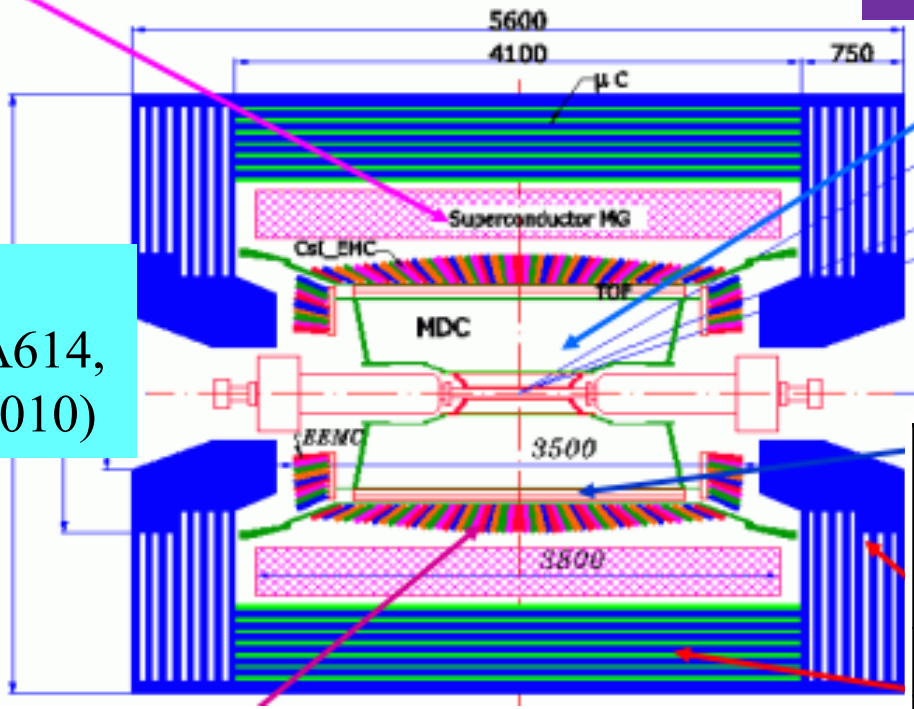
- $J/\psi \to D^0 e^+ e^- + c.c.$ and $\psi(3686) \to D^0 e^+ e^- + c.c.$ *Phys. Rev. D96,111101 (RC) (2017)*
- Search $\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^- +$ c.c. *Phys. Rev. D 97, 091102(RC)(2018)*
- Search for $D \to h(h')ee$ *Phys. Rev. D 97, 072015 (2018)*
- Search for $D^+ \to h^+ e^+ e^-$ and $D^+ \to h^- e^+ e^+$ *BESIII preliminary*

More BESIII new physics search results:
Shenjian Chen's talk, July 5 @DM session

BESIII@BEPCII

peak lumi of 1×10^{33} cm^{-2}s^{-1} at 1.89GeV reached in April 2016

Magnet: 1 T Super conducting



Ref:
NIM A614, 345 (2010)

~ 1.3B +4.7B J/ψ ~ 100×BESII
~ 0.5 B $\psi(3686)$ ~ 24×CLEO-c
~ 2.9/fb $\psi(3770)$ ~ 3.5×CLEO-c

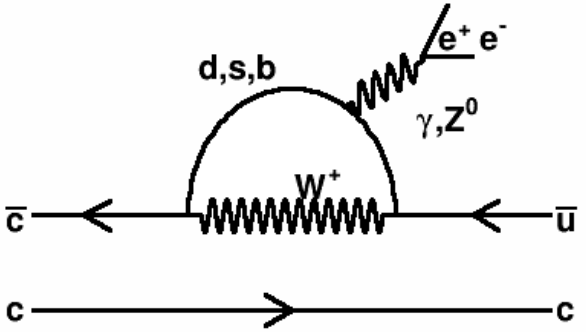
Data sets for results in this talk

Exps.	MDC Spatial resolution	MDC dE/dx resolution	EMC Energy resolution
CLEO-c	110 μm	5%	2.2-2.4 %
BaBar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII	115 μm	<5% (Bhabha)	2.4%

high lumi, large datasets, hermetic detector with good performance and clean environment at BESIII are helpful for probing rare FCNC decays

competitive in channels with low energy electron/photons, neutrons, pi0's

Search for the rare decays J/ψ→ $D^0e^+e^- + c.c.$ and ψ(3686)→ $D^0e^+e^- + c.c.$



dataset: 1310M J/ψ and 448M $\psi(3686)$

With D decay modes:

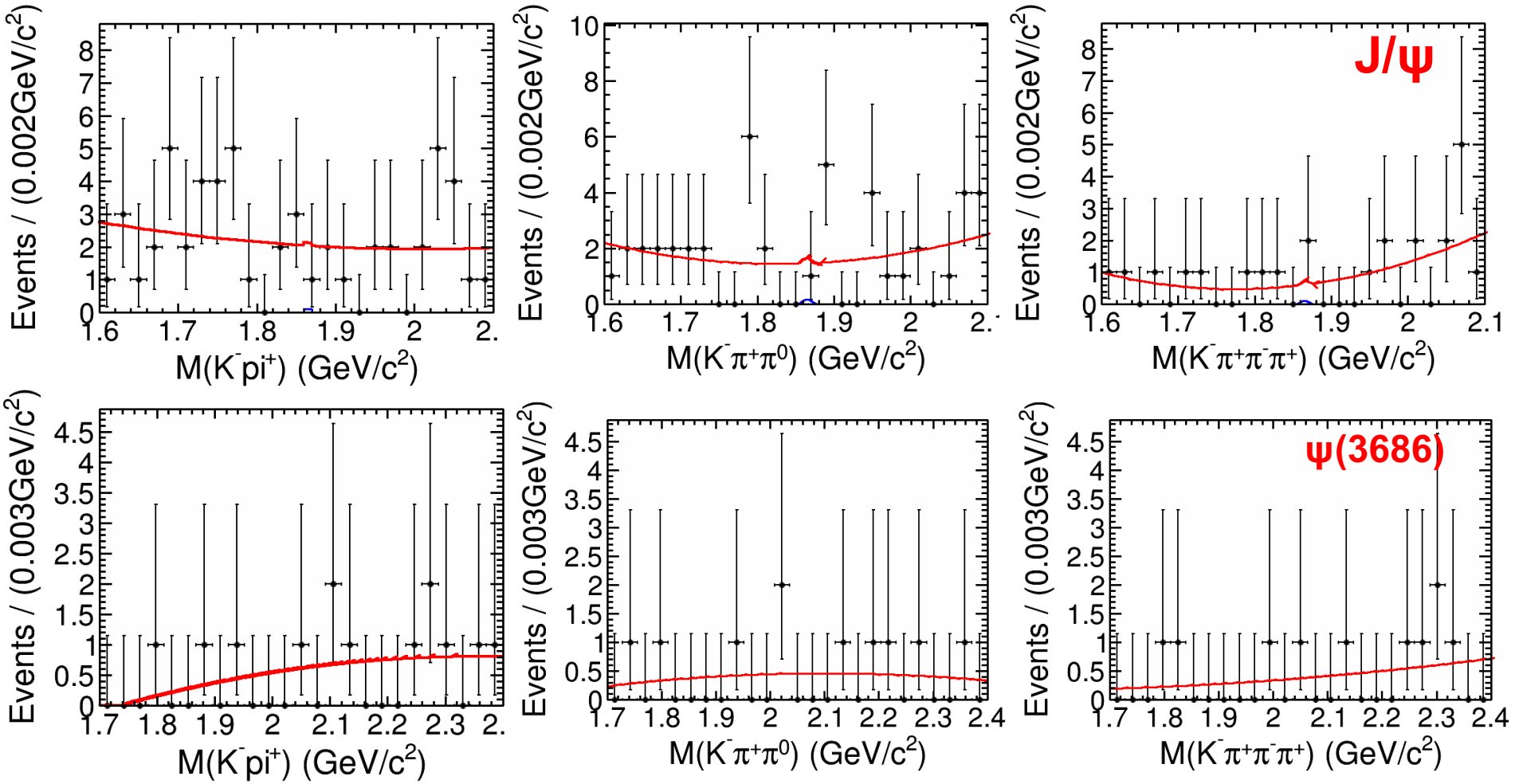
$D^0 \to K^-\pi^+$

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

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

Published at Phys. Rev. D96,111101(2017) (RC)

Fitting of D^0 mass spectra



Simultaneous fit for three decay channels.

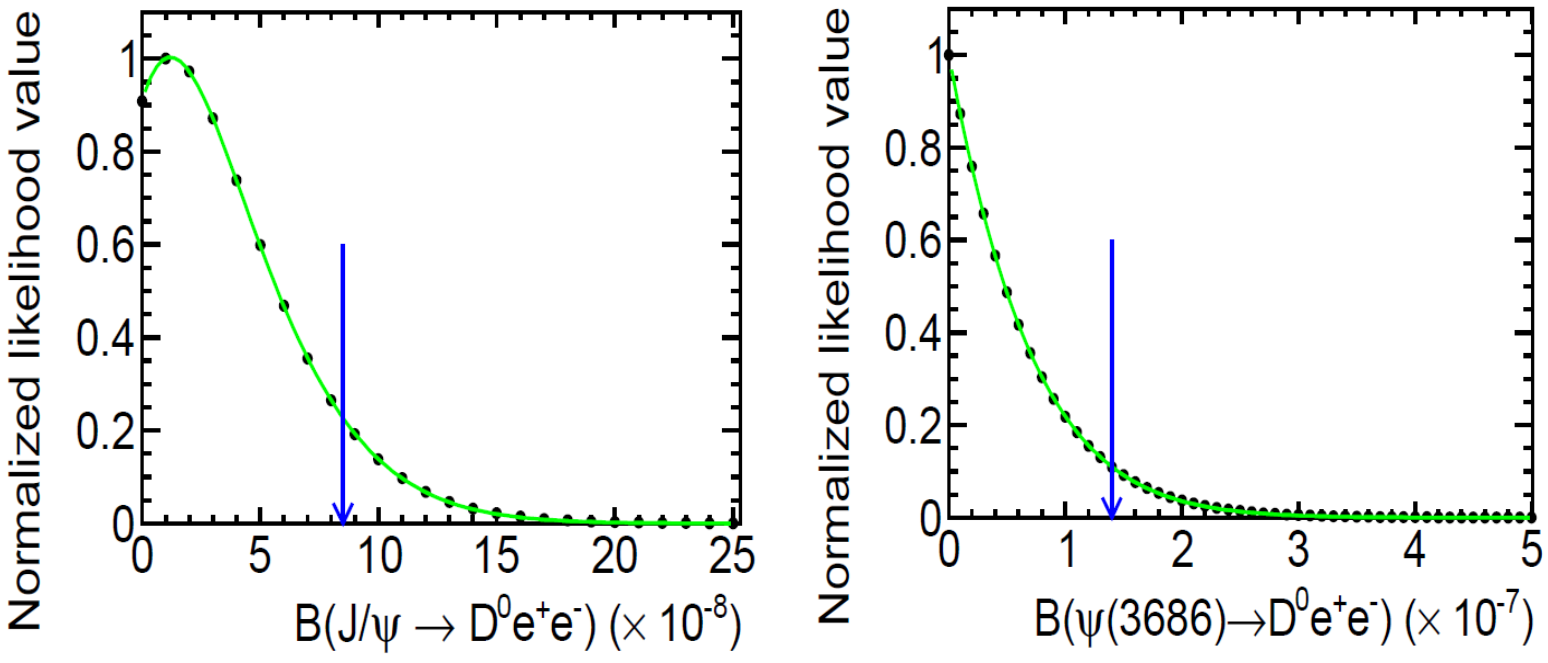
Systematic Uncertainties

	$D^0 \to K^-\pi^+$		$D^0 \to K^-\pi^+\pi^0$		$D^0 \to K^-\pi^+\pi^+\pi^-$	
	J/ψ	$\psi(3686)$	J/ψ	$\psi(3686)$	J/ψ	$\psi(3686)$
Tracking*	4.0	4.0	4.0	4.0	6.0	6.0
PID*	6.0	6.0	6.0	6.0	8.0	8.0
γ detection	...	...	1.2	1.2	...	...
Kinematic fit	1.7	1.6	1.1	1.8	2.2	2.0
Veto γ conversion*	1.7	1.7	1.7	1.7	1.7	1.7
Veto $K_S \to \pi^0\pi^0$	...	...	0.6	...	...	
Veto $K_S \to \pi^+\pi^-$	...	...	...	...	2.1	2.2
Veto $J/\psi \to e^+e^-$	...	0.1	...	...		...
Branching fraction	1.3	1.3	3.6	3.6	2.6	2.6
ψ total number*	0.55	0.62	0.55	0.62	0.55	0.62
Others	1.0	1.0	1.0	1.0	1.0	1.0
Total	7.8	7.8	8.5	8.7	11.0	10.9

The Upper Limits on BRs

combining three D decay channels

Phys. Rev. D96,111101(2017) (RC)

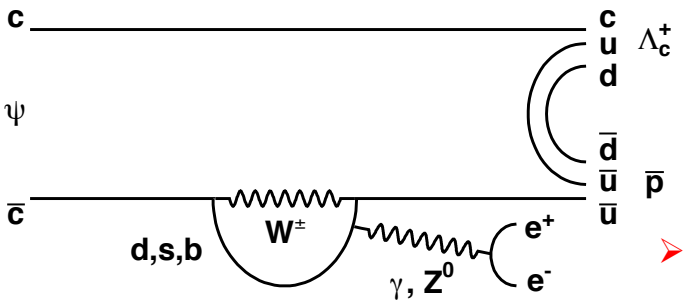


Considering the systematic uncertainty, at 90%C.L.

J/ψ→ $D^0e^+e^- + c.c.$ < 8.5×10^{-8} more stringent by 2 orders in magnitude compared to the previous results Phys. Lett. B 639, 418 (2006).

ψ(3686)→ $D^0e^+e^- + c.c.$ < 1.4×10^{-7} set for the first time

Search $\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^-$ + c.c.



Event selection

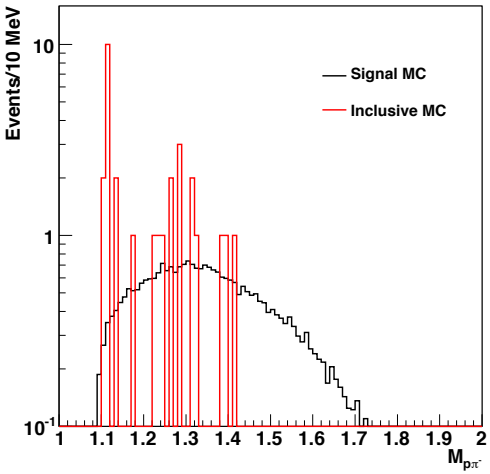
- $\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^-$ + c.c.
  - $\Lambda_c^+ \to p\, K^-\, \pi^+$
- Final state
  - $p\, \bar{p}\, K^-\, \pi^+ (K^+ \pi^-) e^+ e^-$

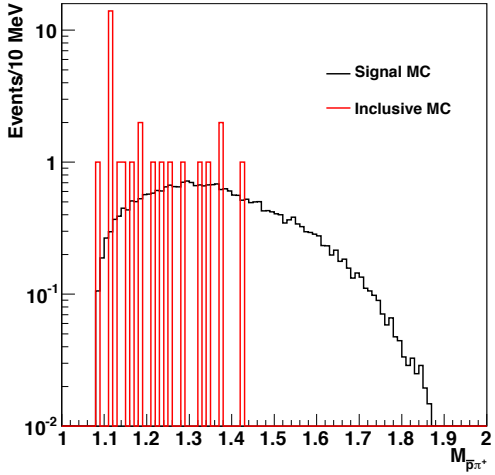
- At least 3 positive and 3 negative charged tracks are required with zero net charge
- partID, vertexFit, 4CFit
- Define 2.25≤ $m(\Lambda_c^+)$ ≤2.32 GeV as signal region (>99%)

New physics models predict the BR could reach ~10^{-6}

Phys. Rev. D 60, 014011(1999);
Nucl. Phys. 25, 461 (2001);

- 29 simulated events remain after 4C kinematic fit, from inclusive $\psi(3686)$ MC sample of 506 M events.
- Most of the background contain Λ or $\bar{\Lambda}$ particle.





- To further remove the background,
  - $M(\bar{p}\pi^+)$>1.13 GeV and $M(p\pi^-)$> 1.13 GeV

The continuum background in the $\psi(3686)$ data is negligible.

$\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^-$ Syst. Unc.

sources	systematic uncertainty(%)
Number of $\psi(3686)$	0.6
Track reconstruction	9.0
Particle identification	9.0
4C kinematic fit	1.0
BF($\Lambda_c^+ \to p\, K^-\, \pi^+$)	5.2
Signal region	4.0
Λ mass window	1.0
Physics model	34.3
Total	37.2

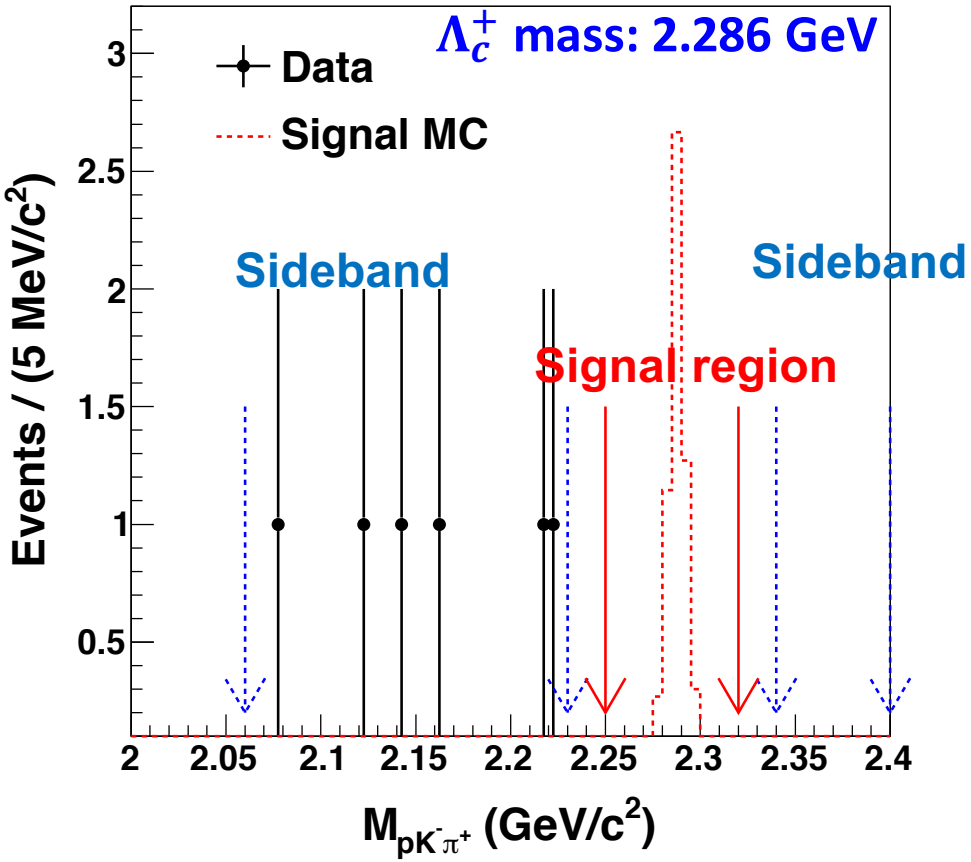
Physics model:

- Nominal:
  - VMD model with FF from $\rho \to \pi^+\pi^- e^+ e^-$
- 1)Extreme case
  - $\psi(2S) \to X\, \bar{p}$; $1+\cos^2\theta$
  - $X \to \Lambda_c^+ e^+ e^-$ (VMD); 7.2%→4.7%
- 2) PHSP model. 7.2%→6.6%

$\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^-$ search result

Signal region:2.25-2.32 GeV.

Λ_c^+ mass: 2.286 GeV



Phys. Rev. D 97, 091102(RC)(2018)

- No signal is found.
- the 90% C.L. upper limit (Nup=47.3) is obtained taking into account the efficiency and systematic uncertainties.

Nucl. Instrum. Methods A 551 (2005) 493– 503.

- The BF upper limit @90% C.L. is determined to be 1.7×10^{-6} with systematic uncertainties taken into account.

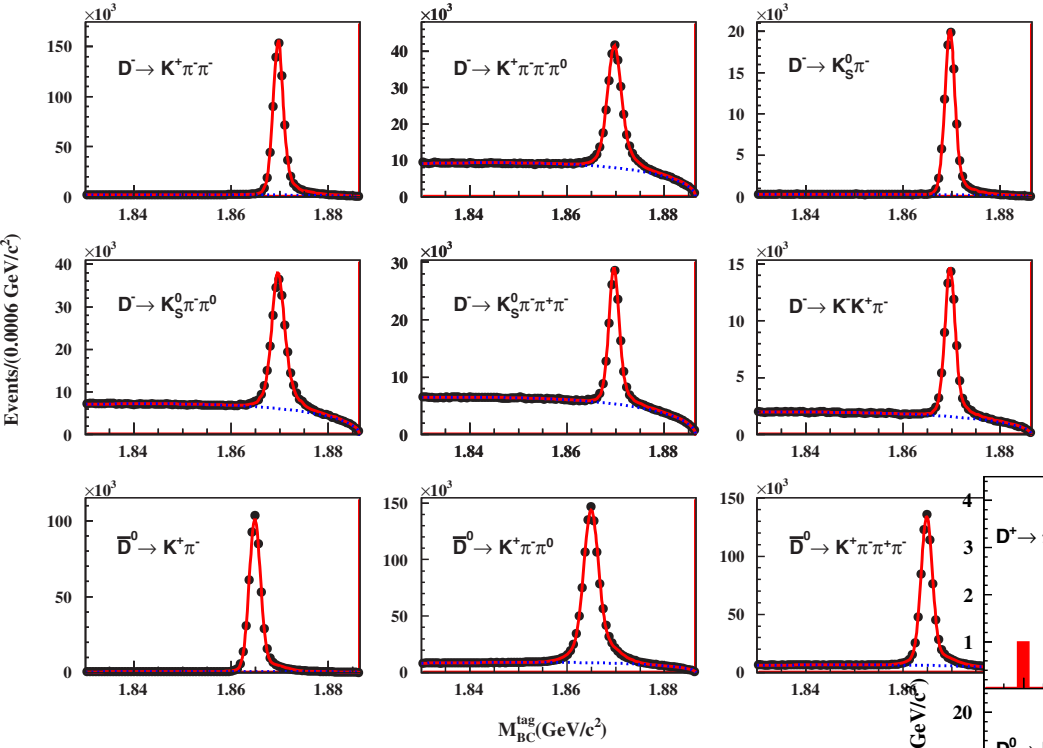
D->h(h')ee: previous results

Decay	Upper limit	Experiment	Year	Ref.
$D^0 \to \pi^0 e^+ e^-$	45.0	CLEO	1996	[14]
$D^0 \to \eta e^+ e^-$	110.0	CLEO	1996	[14]
$D^0 \to \omega e^+ e^-$	180.0	CLEO	1996	[14]
$D^0 \to \overline{K}^0 e^+ e^-$	110.0	CLEO	1996	[14]
$D^0 \to \rho e^+ e^-$	124.0	E791	2001	[15]
$D^0 \to \phi e^+ e^-$	59.0	E791	2001	[15]
$D^0 \to \overline{K}^{*0} e^+ e^-$	47.0	E791	2001	[15]
$D^0 \to \pi^+ \pi^- e^+ e^-$	370.0	E791	2001	[15]
$D^0 \to K^+ K^- e^+ e^-$	315.0	E791	2001	[15]
$D^0 \to K^- \pi^+ e^+ e^-$	385.0	E791	2001	[15]
$D^+ \to \pi^+ e^+ e^-$	1.1	BaBar	2011	[16]
$D^+ \to K^+ e^+ e^-$	1.0	BaBar	2011	[16]
$D^+ \to \pi^+ \pi^0 e^+ e^-$				
$D^+ \to \pi^+ K^0_S e^+ e^-$				
$D^+ \to K^+ \pi^0 e^+ e^-$				
$D^+ \to K^+ \overline{K}^0 e^+ e^-$				

In unit of 10^{-6}

- Previous D^0 limits are in the level of 10^{-5} ~10^{-4}
- D^+ limits are better, but only few three-body decays
- LHCb observed some four-body decays of $D^0 \to hh\mu^+\mu^-$ at 10^{-7} level
- BESIII could probe all of the above e+e- modes

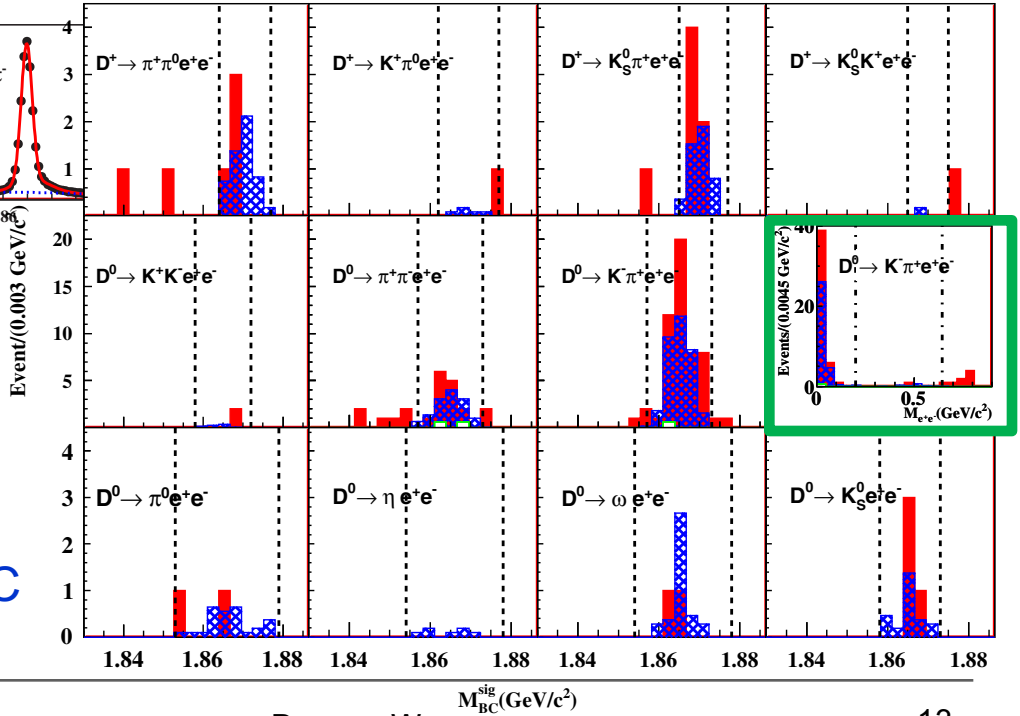
Double tag(DT) analysis



DT: Fully make use of DD pair production at threshold

- Event is very clean, bkg low
- High tagging efficiency
- Many systematic uncertainties can be cancelled
- Could measure absolute BFs

Blind analysis based on Monte Carlo (MC) simulations to validate the analysis strategy,



Data
Inclusive MC
sideband

D→h(h′)ee: BESIII results

Signal decays	$\mathcal{B}$ ($\times 10^{-5}$)	PDG [9] ($\times 10^{-5}$)
$D^+ \to \pi^+\pi^0 e^+e^-$	<1.4	...
$D^+ \to K^+\pi^0 e^+e^-$	<1.5	...
$D^+ \to K^0_S\pi^+ e^+e^-$	<2.6	...
$D^+ \to K^0_S K^+ e^+e^-$	<1.1	...
$D^0 \to K^-K^+ e^+e^-$	<1.1	<31.5
$D^0 \to \pi^+\pi^- e^+e^-$	<0.7	<37.3
$D^0 \to K^-\pi^+ e^+e^-{}^\dagger$	<4.1	<38.5
$D^0 \to \pi^0 e^+e^-$	<0.4	<4.5
$D^0 \to \eta e^+e^-$	<0.3	<11
$D^0 \to \omega e^+e^-$	<0.6	<18
$D^0 \to K^0_S e^+e^-$	<1.2	<11
† in $M_{e^+e^-}$ regions:		
$[0.00, 0.20)$ GeV/c^2	<3.0 $(1.5^{+1.0}_{-0.9})$	...
$[0.20, 0.65)$ GeV/c^2	<0.7	...
$[0.65, 0.90)$ GeV/c^2	<1.9 $(1.0^{+0.5}_{-0.4})$	...

- With double tag technique at threshold, both D^0 and D^+ FCNC are studied.
- UL for D^+ 4-track events are provided for 1st time
- other FCNC upper limits are greatly improved
- divide the M(ee) distribution into 3 regions for Kpiee to help separate LD effect

Phys. Rev. D 97, 072015 (2018)

$D^+ \to h^+e^+e^-$ and $D^+ \to h^-e^+e^+$

- FCNC (e.g. $D^+ \to h^+e^+e^-$) processes are expected to be very rare since it can not occur at tree level in the SM.

Short distance: ~ $10^{-10\sim-9}$ level, MPLA8 (1993) 967

Long distance: ~ $10^{-6\sim-5}$ level, PRD76 (2007) 074010

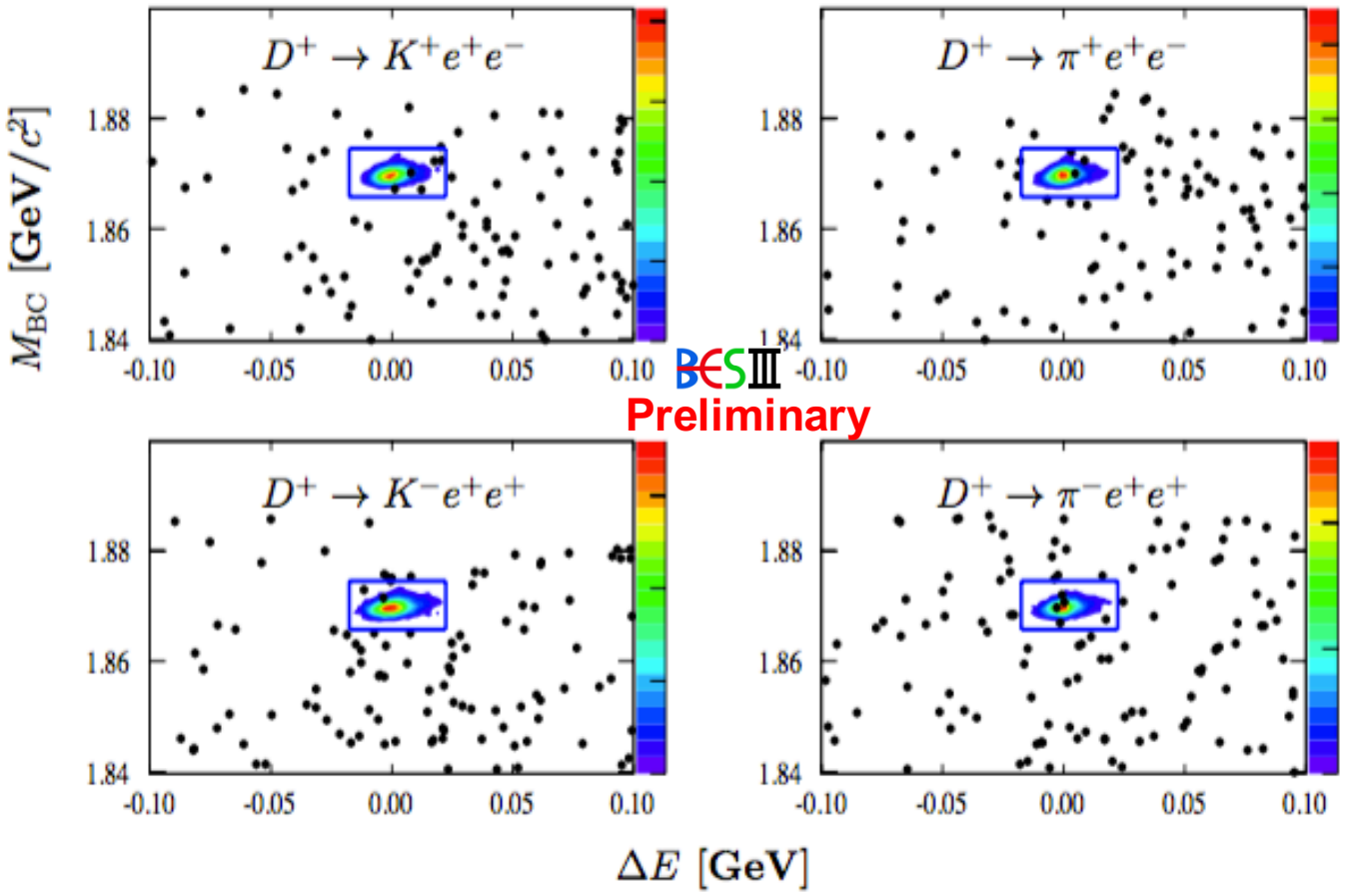
- Lepton Number Violation (LNV) (e.g. $D^+ \to h^-e^+e^+$) decays are forbidden in the SM, while beyond the SM

Majorana neutrino: ~ $10^{-30\sim-23}$ level, PRD64 (2001) 114009

may be greatly enhanced to ~$10^{-5\sim-6}$, EPJC71 (2011) 1715

$\mathcal{B}(D^+ \to) \setminus [\times 10^{-6}]$	$K^+e^+e^-$	$K^-e^+e^+$	$\pi^+e^+e^-$	$\pi^-e^+e^+$
CLEO[1]	-	-	2600	-
MARK2[2]	4800	9100	2500	4800
E687[3]	200	120	110	110
E791[4]	200	-	52	96
CLEO[5]	3.0	3.5	5.9	1.1
Babar[6]	1.0	0.9	1.1	1.9
PDG[7]	1.0	0.9	1.1	1.1

$D^+ \to h^+ ee$ data unblinded



Scatter plots for M_{BC} versus ΔE, where the signal regions are shown as a blue rectangle. The contours are determined from MC simulation to enclose 84% of signal events for each channel.

$D^+ \to h^+ ee$ preliminary results

BESIII Preliminary

	$N^{\rm data}_{\rm inside}$	$N^{\rm data}_{\rm outside}$	$f_{\rm scale}$	ϵ [%]	$\Delta_{\rm sys}$ [%]	s_{90}	$\mathcal{B}[\times 10^{-6}]$
$D^+ \to K^+e^+e^-$	5	69	0.08 ± 0.01	22.53	5.4	19.4	< 1.2
$D^+ \to K^-e^+e^+$	3	55	0.08 ± 0.01	24.08	6.1	10.2	< 0.6
$D^+ \to \pi^+e^+e^-$	3	65	0.09 ± 0.02	25.72	5.9	4.2	< 0.3
$D^+ \to \pi^-e^+e^+$	5	68	0.06 ± 0.02	28.08	6.8	20.5	< 1.2

While s_{90} is estimated with **TROLKE** program, and the upper limit of branching fraction is calculated by

$$\mathcal{B} < \frac{s_{90}}{N^{\rm tot}_{D^+}}$$

where $N^{\rm tot}_{D^+} = (1.681 \pm 0.032) \times 10^7$

Search for $D^0 \to \pi^0 \nu\bar{\nu}$:

- EM dynamics is absent
- LD contributions are much suppressed
- Much clean to probe FCNC transitions in charm
- Could be complementary to results from B mesons
  - Belle B → h(*) νν: Phys. Rev. Lett. 99, 221802 (2007).
  - BaBar B⁰ →γνν: Phys. Rev. Lett. 93, 091802 (2004).

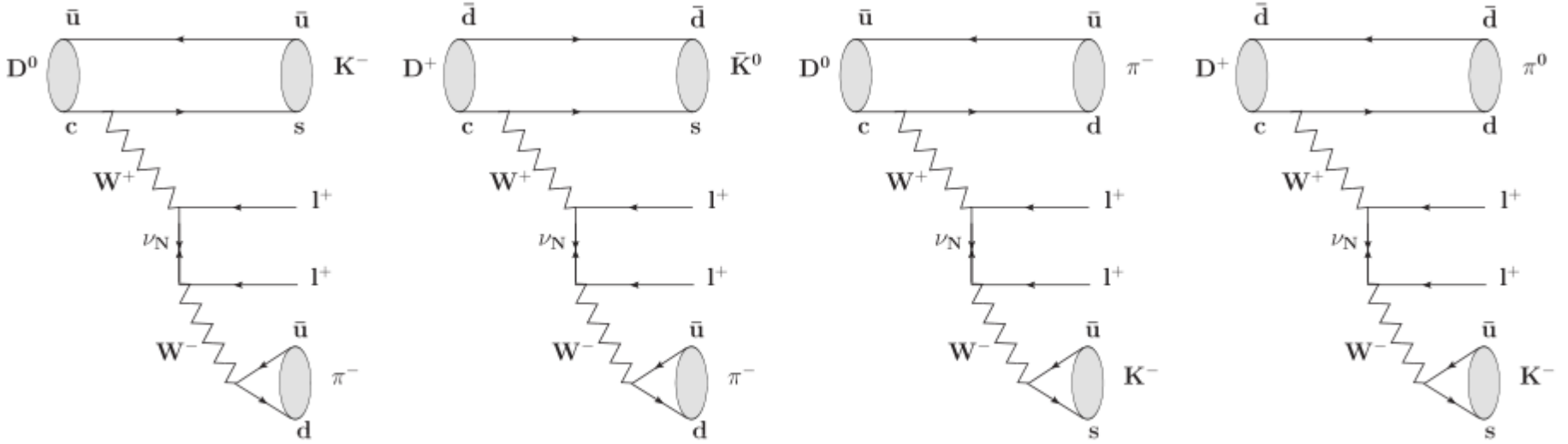
Decay mode	Experimental limit	$\mathcal{B}r_{S.D.}$	$\mathcal{B}r_{L.D.}$
$D^+ \to X_u^+ e^+ e^-$		2×10^{-8}	
$D^+ \to \pi^+ e^+ e^-$	$<4.5\times10^{-5}$		2×10^{-6}
$D^+ \to \pi^+ \mu^+ \mu^-$	$<1.5\times10^{-5}$		1.9×10^{-6}
$D^+ \to \rho^+ e^+ e^-$	$<1.0\times10^{-4}$		4.5×10^{-6}
$D^0 \to X_u^0 e^+ e^-$		0.8×10^{-8}	
$D^0 \to \pi^0 e^+ e^-$	$<6.6\times10^{-5}$		0.8×10^{-6}
$D^0 \to \rho^0 e^+ e^-$	$<5.8\times10^{-4}$		1.8×10^{-6}
$D^0 \to \rho^0 \mu^+ \mu^-$	$<2.3\times10^{-4}$		1.8×10^{-6}
$D^+ \to X_u^+ \nu\bar{\nu}$		1.2×10^{-15}	
$D^+ \to \pi^+ \nu\bar{\nu}$			5×10^{-16}
$D^0 \to \bar{K}^0 \nu\bar{\nu}$			2.4×10^{-16}
$D_s \to \pi^+ \nu\bar{\nu}$			8×10^{-15}

Pure neutral final state with missing momenta.
Unique for BESIII,
Work ongoing

Phys. Rev. D 66 014009

Search for $D \to K\pi e^+e^+$ decays

H.R. Dong et al Chin, Phys. C **39** 013101 (2015).



- Lepton number violating(LNV) process ($\Delta L = 2$)
  - possibly due to a single Majorana neutrino exchange
- The best BR limit around 10^{-4} ~10^{-5} level by E791[PRL 86, 3969(2001)].
- BESIII could improve them to ~10^{-6}
- Further constrain mass-dependent $D \to Ke^+\nu_N(\pi e^+)$ decay
  - constrain mixing matrix element $|V_{eN}|^2$
- Work in progress, the results to be published

Summary

- **FCNC transitions are sensitive probes of new physics**
- **BESIII searches of FCNC in charmonium and charm meson decays provide the best limits on:**
  - $J/\psi \to D^0 e^+ e^-$ and $\psi(3686) \to D^0 e^+ e^-$ *Phys. Rev. D96,111101 (RC) (2017)*
  - Search $\psi(3686) \to \Lambda_c^+ \bar{p}\, e^+ e^-$ *Phys. Rev. D 97, 091102(RC)(2018)*
  - Search for $D \to h(h')ee$ *Phys. Rev. D 97, 072015 (2018)*
  - Search for $D^+ \to h^+ e^+ e^-$ and $D^+ \to h^- e^+ e^+$ *BESIII preliminary*
- **BESIII has great potential with unique (and increasing) datasets for new physics search:**
  - **More to come, stay tuned!**

More BESIII new physics search results:
Shenjian Chen's talk, July 5 @DM session