

Charmonium weak decays at BESIII

Ziyuan Li

Sun Yat-sen University, China

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Outline

- Charmonium weak decays
 - Weak semi-leptonic decay
 - FCNC weak semi-leptonic decay
 - Weak hadronic decay
- BEPCII & BESIII
- Charmonium weak decays at BESIII
- Summary and Future

Charmonium weak decays

- The decays of J/ψ are dominated by strong and electromagnetic interactions
- Weak decays, due to the smallness of the strength of the weak interaction, are rare processes
- The decay rate is $\propto G_F^5 m_c^5$, which is at the order of 10^{-11}
- The inclusive weak decay rate of J/ψ : $Br \approx \frac{2/\tau_D}{\Gamma_{J/\psi}} \approx 10^{-8}$
- Study of Charmonium weak decays
 - **Provide a further accurate examination of the mechanism**
 - **Probe new physics beyond the standard model**

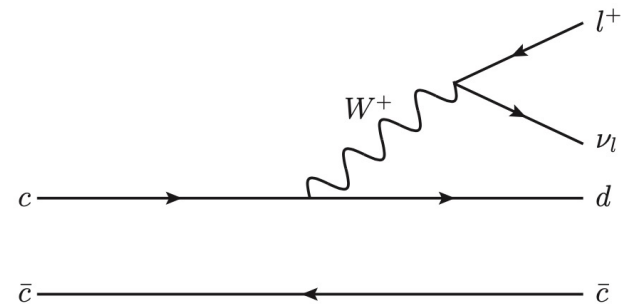
[1]Z.Phys.C.62.271 (1994) [2]EPJC,54,107 (2008) [3]PRD,78:074012 (2008)
[4]AHEP,2013:706543 (2013) [5]PRD,92:074030 (2015) [6]JPG:NPP,44:045004 (2017)

Weak semi-leptonic decay

The branching ratios of semi-leptonic decays of J/ψ ($\times 10^{-11}$)

Channel	QCDSR [1]	CLFQ [2]	BSW [3]	CCQM [4]	BSM [5]
$J/\psi \rightarrow D^- e^+ \nu_e$	$0.73^{+0.43}_{-0.22}$	5.1-5.7	$6^{+0.8}_{-0.7}$	1.71	$2.03^{+0.29}_{-0.25}$
$J/\psi \rightarrow D^- \mu^+ \nu_\mu$	$0.71^{+0.43}_{-0.22}$	4.7-5.5	$5.8^{+0.8}_{-0.6}$	1.66	$1.98^{+0.28}_{-0.24}$
$J/\psi \rightarrow D_s^- e^+ \nu_e$	18^{+7}_{-5}	53-58	$104^{+9}_{-7.5}$	33	$36.7^{+5.2}_{-4.4}$
$J/\psi \rightarrow D_s^- \mu^+ \nu_\mu$	17^{+7}_{-5}	55-57	$99.3^{+9.5}_{-6.5}$	32	$35.4^{+5.0}_{-4.3}$

BR can be enhanced in Top-color model,
the Minimal Supersymmetric SM with R-
parity, the two-Higgs doublet model [6-8]



[1]EPJC,54:107 (2008)

[4]PRD,92:074030 (2015)

[7]PLB,345:483 (1995)

[2]PRD,78:074012 (2008)

[5]JPG:NPP,44:045004 (2017)

[8]PRD,15:1958 (1977)

[3]AHEP,2013:706543 (2013)

[6]PRD, 60:014011 (1999)

FCNC weak semi-leptonic decay

- Forbidden at tree level by GIM mechanism
- Can occur via a $c \rightarrow u$ transition at the loop level

QCDSR[1] :

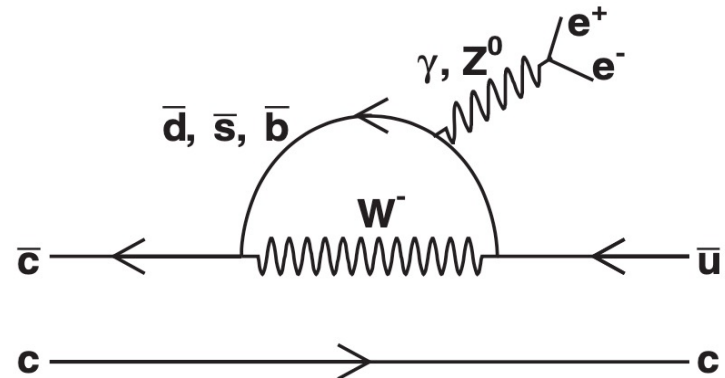
$$Br(J/\psi \rightarrow \bar{D}^0 e^+ e^-) = 4.8_{-1.5}^{+3.0} \times 10^{-14}$$

$$Br(J/\psi \rightarrow \bar{D}^{*0} e^+ e^-) = 2.7_{-1.0}^{+1.5} \times 10^{-13}$$

$$Br(J/\psi \rightarrow \bar{D}^0 \mu^+ \mu^-) = 4.5_{-1.4}^{+2.8} \times 10^{-14}$$

$Br(J/\psi \rightarrow \bar{D}^{*0} \mu^+ \mu^-) = 2.5_{-0.9}^{+1.4} \times 10^{-13}$

New Physics model [2-4] predict that the Br can be enhanced by 2 to 3 orders of magnitude



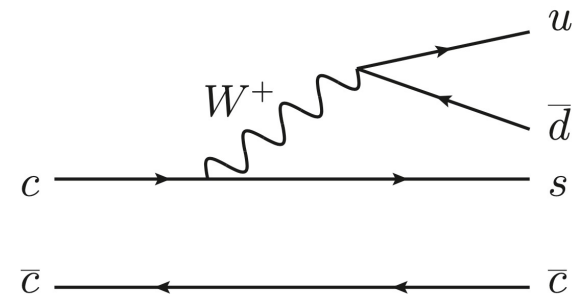
Weak hadronic decay

- Examine the mechanism that governs the hadronization process

The branching ratios of non-leptonic decays of J/ψ for the Cabibbo-favored and color-favored channel ($\times 10^{-10}$)

Channel	QCDSR [1]	BSW [2]	QCDF [3]	BSM [4]
$J/\psi \rightarrow D_s^- \pi^+$	$2^{+0.4}_{-0.2}$	$14.82^{+0.26}_{-0.46}$	21.8	$4.75^{+0.67}_{-0.59}$
$J/\psi \rightarrow D_s^- \rho^+$	12.6^{+3}_{-1}	$102.0^{+15.2}_{-12.0}$	76.4	$1.98^{+0.28}_{-0.24}$
$J/\psi \rightarrow D_s^{*-} \pi^+$	$15^{+1.2}_{-0.4}$	/	/	$25.7^{+3.4}_{-3.1}$
$J/\psi \rightarrow D_s^{*-} \rho^+$	$52.6^{+7.2}_{-6.2}$	/	/	$58.6^{+7.8}_{-6.7}$

New Physics model [5-7] predict that the Br can be enhanced to 10^{-5}



[1]EPJC,54:107 (2008)

[4]PRD,15:1958 (1977)

[7]PRD,15:1958 (1977)

[2] AHEP,2013:706543 (2013)

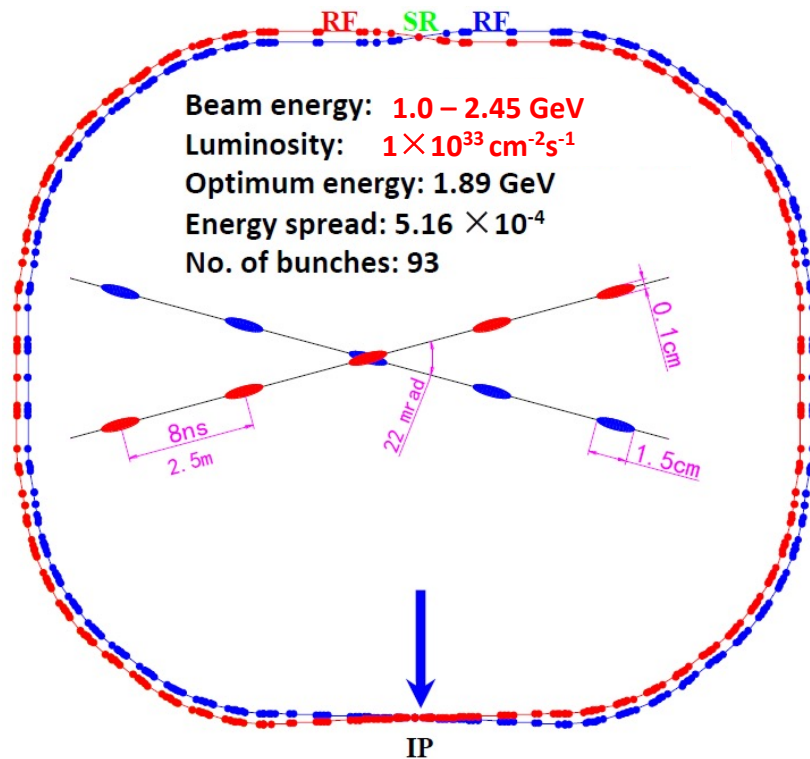
[5]PRD, 60:014011 (1999)

[3]AHEP,2016:5071671(2016)

[6]PLB,345:483 (1995)

BEPCII and BESIII

Beijing Electron Positron Collider II

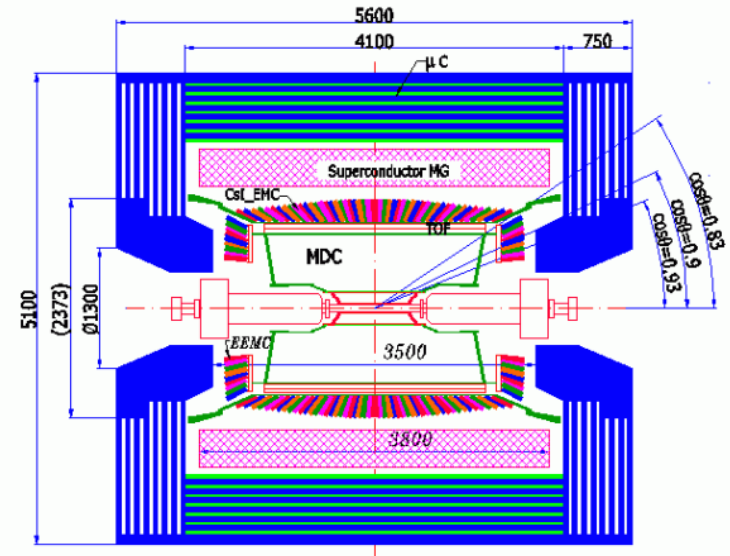


Charm Factory

BESIII Detector

MDC: p 0.5% @ 1GeV/c
 dE/dx: 6%

EMC: CsI (TI) 2.5% (5.0%)
 barrel (endcap) @ 1GeV



TOF: $\sigma T = 68(65)$ ps
 barrel (endcap)

MUC: RPC 9 (8) layers
 barrel (endcap)

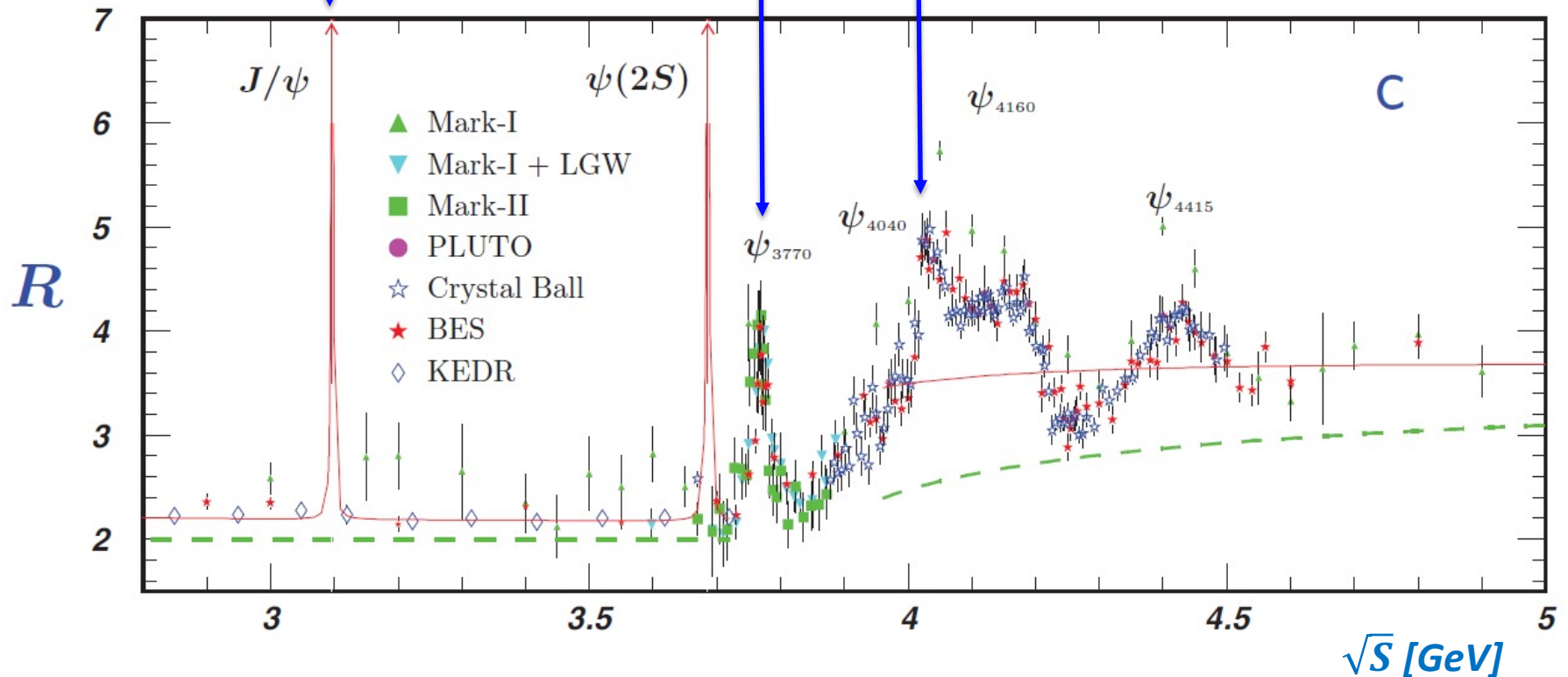
Charmonium data at BESIII

$\psi(3686)$ 3.0×10^9

$\psi(3770)$ 2.9 fb^{-1}

$\psi(4040)$ 0.5 fb^{-1}

J/ψ 1.0×10^{10}



Charmonium weak decays at BESIII

10 Billion J/ψ , 3 Billion $\psi(3686)$

- Precise tests of SM
- Constrain model parameters
- Search for new physics BSM

BESIII Charmonium weak decays publications

Physics		Processes	Publication
Weak Decays	Semi-leptonic	$J/\psi \rightarrow D_s^{(*)-} e^+ \nu_e$	PRD 90, 112014 (2014)
		$J/\psi \rightarrow D^- e^+ \nu_e$	JHEP 06, 157 (2021)
	FCNC	J/ψ and $\psi(3686) \rightarrow D^0 e^+ e^-$	PRD 96, 111101 (2017)
		$\psi(3686) \rightarrow A_c^+ \bar{p} e^+ e^-$	PRD 97, 091102 (2018)
	Hadronic	$J/\psi \rightarrow D_s^- \rho^+$ and $J/\psi \rightarrow \bar{D}^0 \bar{K}^{*0}$	PRD 89, 071101 (2014)

New

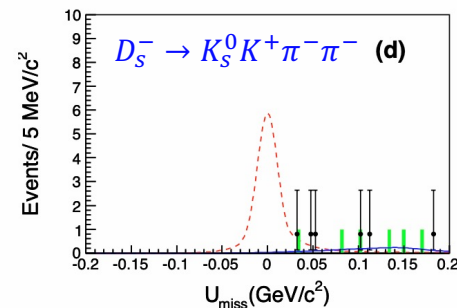
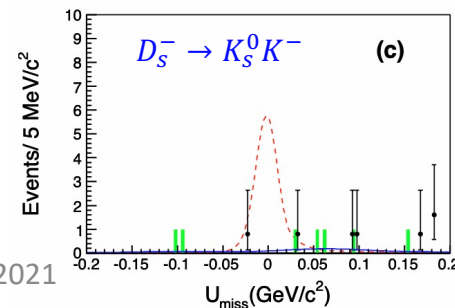
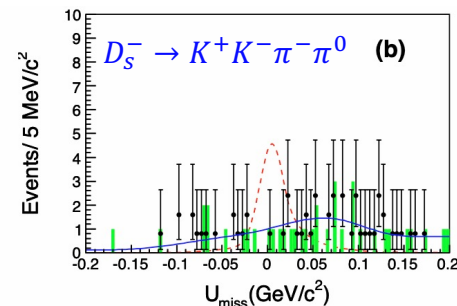
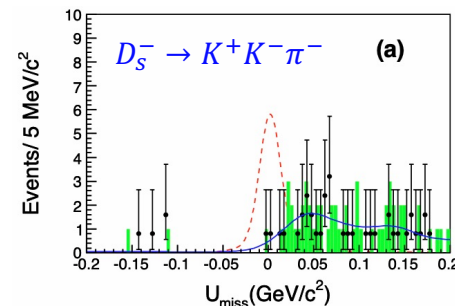
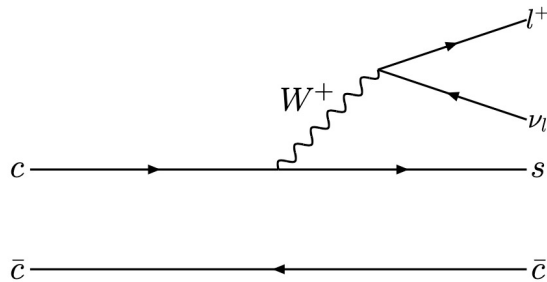
$$J/\psi \rightarrow D_s^{(*)-} e^+ \nu_e$$

PRD 90, 112014 (2014)

- 225 million J/ψ
- First search of $J/\psi \rightarrow D_s^{*-} e^+ \nu_e$
- D_s^- reconstruct via 4 decays modes, D_s^{*-} reconstruct with $D_s^- \gamma$
- Check U_{miss} distribution, no signal is found in the signal region
- Upper limits on BF(90% C.L.)

$$- Br(J/\psi \rightarrow D_s^- e^+ \nu_e) < 1.3 \times 10^{-6}$$

$$- Br(J/\psi \rightarrow D_s^{*-} e^+ \nu_e) < 1.8 \times 10^{-6}$$



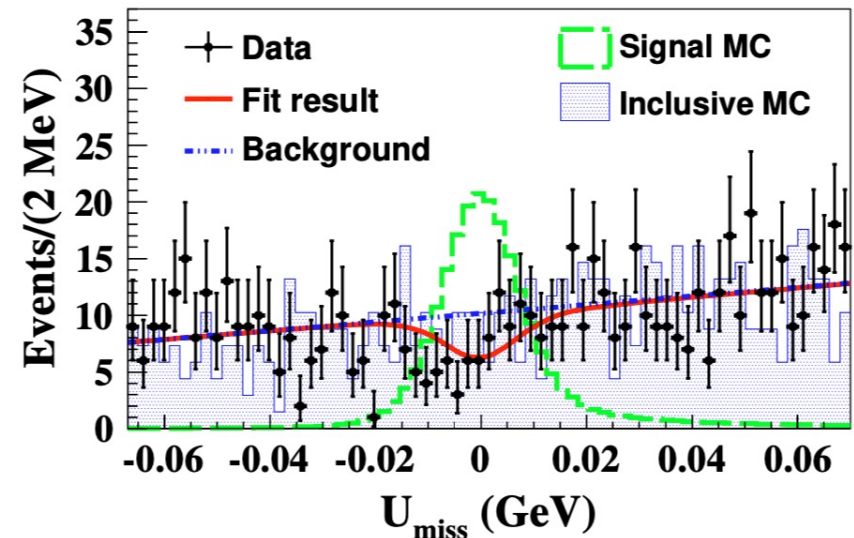
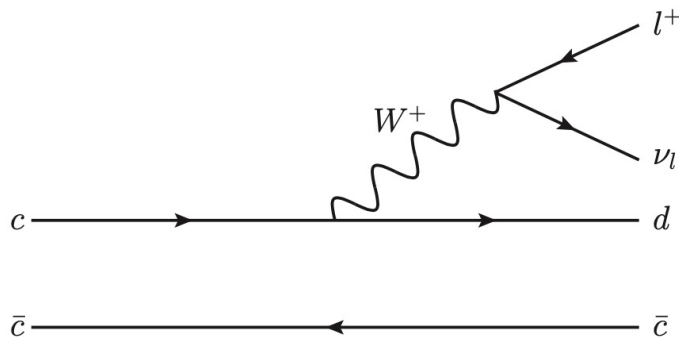
$J/\psi \rightarrow D^- e^+ \nu_e$

JHEP 06, 157 (2021)

- 10 Billion J/ψ
- D^- reconstruct via $K\pi\pi$
- Check U_{miss} distribution, no signal is found in the signal region
- Upper limits on BF(90% C.L.)

$$- Br(J/\psi \rightarrow D^- e^+ \nu_e) < 7.1 \times 10^{-8}$$

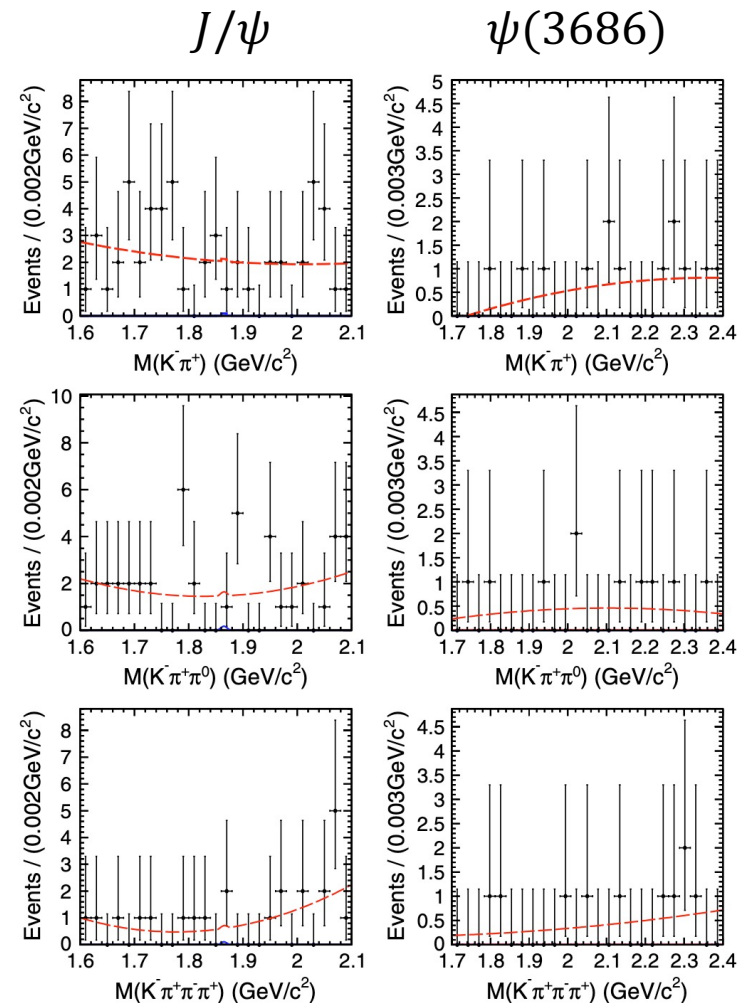
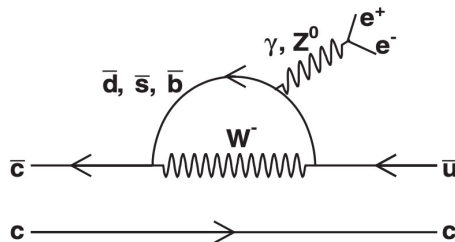
- Improve two orders of magnitude



J/ψ and $\psi(3686) \rightarrow D^0 e^+ e^-$

PRD 96, 111101 (2017)

- 1310 million J/ψ and 448 million $\psi(3686)$
- First search of $\psi(3686) \rightarrow D^0 e^+ e^-$
- Check $M_{K\pi}$, $M_{K\pi\pi^0}$, $M_{K\pi\pi\pi}$ distribution, no signal is found in the signal region
- Upper limits on BF(90% C.L.)
 - $Br(J/\psi \rightarrow D^0 e^+ e^-) < 8.5 \times 10^{-8}$
 - $Br(\psi(3686) \rightarrow D^0 e^+ e^-) < 1.4 \times 10^{-7}$
- Improve two orders of magnitude

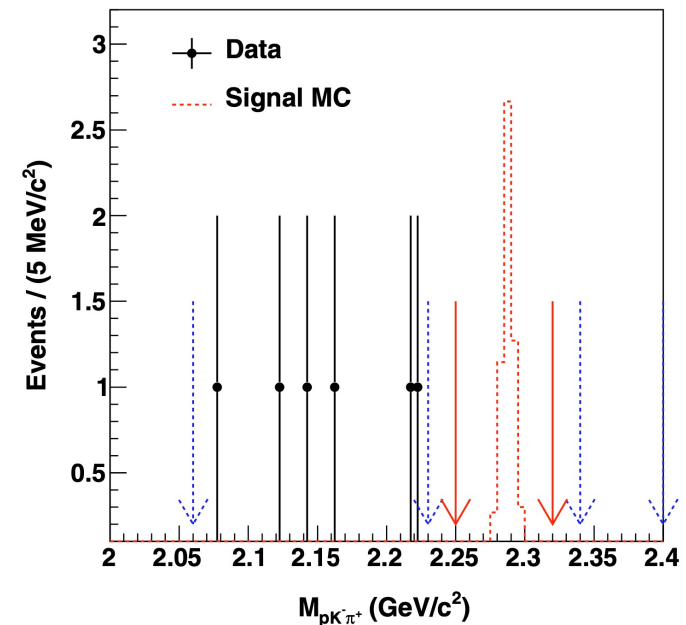
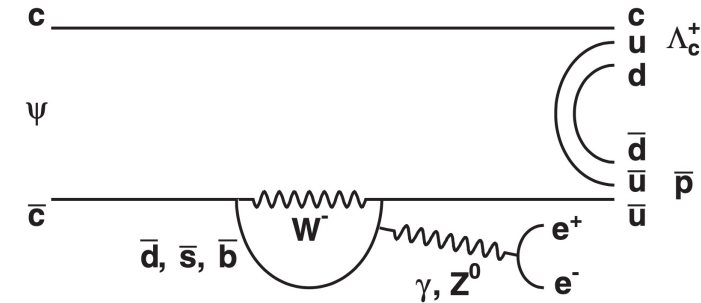


$\psi(3686) \rightarrow \Lambda_c^+ \bar{p} e^+ e^-$

PRD 97, 091102 (2018)

- 448 million $\psi(3686)$
- First search of $\psi(3686) \rightarrow \Lambda_c^+ \bar{p} e^+ e^-$
- Check $M_{pK\pi}$ distribution, no signal is found in the signal region
- Large systematic uncertainty in MC modeling ($\sim 34\%$)
- Upper limits on BF(90% C.L.)

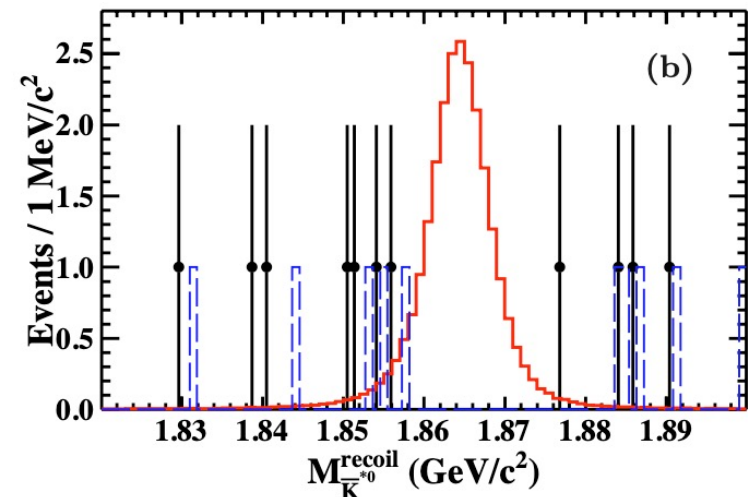
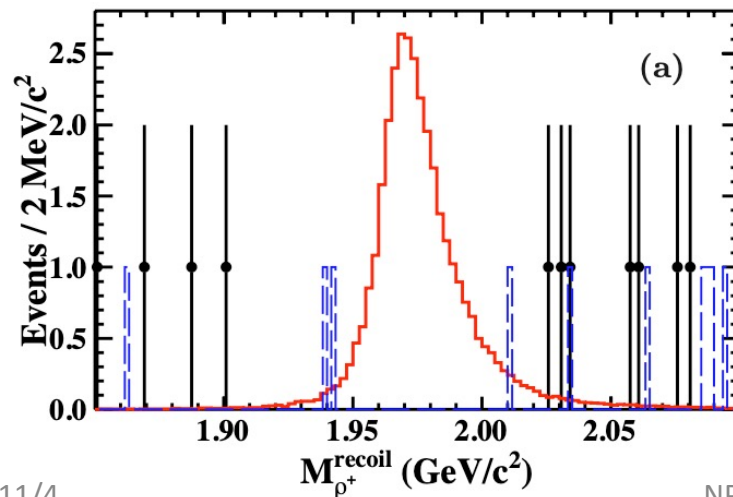
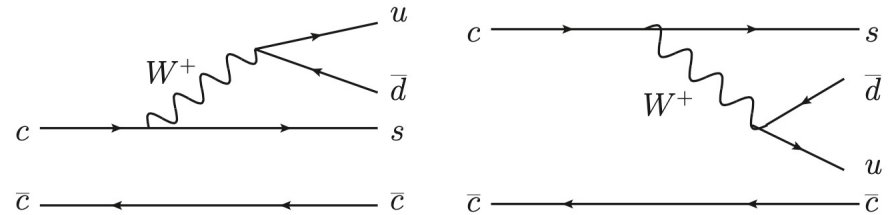
$$- Br(\psi(3686) \rightarrow \Lambda_c^+ \bar{p} e^+ e^-) < 1.7 \times 10^{-6}$$



$J/\psi \rightarrow D_s^- \rho^+$ and $J/\psi \rightarrow \bar{D}^0 \bar{K}^{*0}$

PRD 89, 071101 (2014)

- 225 million J/ψ
- Check $M_\rho, M_{\bar{K}^{*0}}$ distribution, no signal is found in the signal region
- Upper limits on BF(90% C.L.)
 - $Br(J/\psi \rightarrow D_s^- \rho^+) < 1.3 \times 10^{-5}$
 - $Br(J/\psi \rightarrow \bar{D}^0 \bar{K}^{*0}) < 2.5 \times 10^{-6}$



More on going work

- Many Charmonium weak decays study is on going
 - $J/\psi \rightarrow D_s^- e^+ \nu_e$
 - $J/\psi \rightarrow D^- u^+ \nu_u$
 - $J/\psi \rightarrow \bar{D}^0 \pi^0, \bar{D}^0 \rho^0, \bar{D}^0 \eta, D^- \pi^+, D^- \rho^+$
 - ψ' weak decay
 - ...

Summary

- Brief review of Charmonium weak decays at BESIII, no signal observed

Physics		Processes	Publication	Br (90% C.L.)
Weak Decays	Semi-leptonic	$J/\psi \rightarrow D_s^{(*)-} e^+ \nu_e$	PRD 90, 112014 (2014)	$1.3(1.8) \times 10^{-6}$
		$J/\psi \rightarrow D^- e^+ \nu_e$	JHEP 06, 157 (2021)	7.1×10^{-8}
	FCNC	J/ψ and $\psi(3686) \rightarrow D^0 e^+ e^-$	PRD 96, 111101 (2017)	$8.5(14) \times 10^{-8}$
		$\psi(3686) \rightarrow \Lambda_c^+ \bar{p} e^+ e^-$	PRD 97, 091102 (2018)	1.7×10^{-6}
	Hadronic	$J/\psi \rightarrow D_s^- \rho^+$ and $J/\psi \rightarrow \bar{D}^0 \bar{K}^{*0}$	PRD 89, 071101 (2014)	$13(2.5) \times 10^{-6}$

- More potential with larger data sample
 - 1×10^{10} J/ψ
 - 3×10^9 $\psi(3686)$
 - Other Charmonium data in the future

Thank you!