Charmonium weak decay searches at BESIII

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Outline

- **New physics researches at BESIII**
- **Charmonium hadronic weak decays**
- **Charmonium semi-leptonic decays**
- **FCNC decays**
- **Summary**

New physics searches at BESIII

Symmetry

- BNV & LNV processes
- LFV processes
- Other symmetry violation

Very rare

- FCNC processes
- Charmonium weak decays
- Other rare decays

Exotic

- Dark photon
- Invisible signatures
- Light Higgs, Z′
- Exotic resonances

Strategies

- Common statistic and standards
- Sharing methods, tools and codes
- Uniform **semi-blind strategy** and datasets (to avoid a possible bias)

- Nation Science Review 8, nwab189 (2021), arXiv: 2102.13290
- New Physics Program of BES, D.Y. Wang, in "30 Years of BES Physics"

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Outline

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- Charmonium hadronic weak decays
- Charmonium semi-leptonic decays
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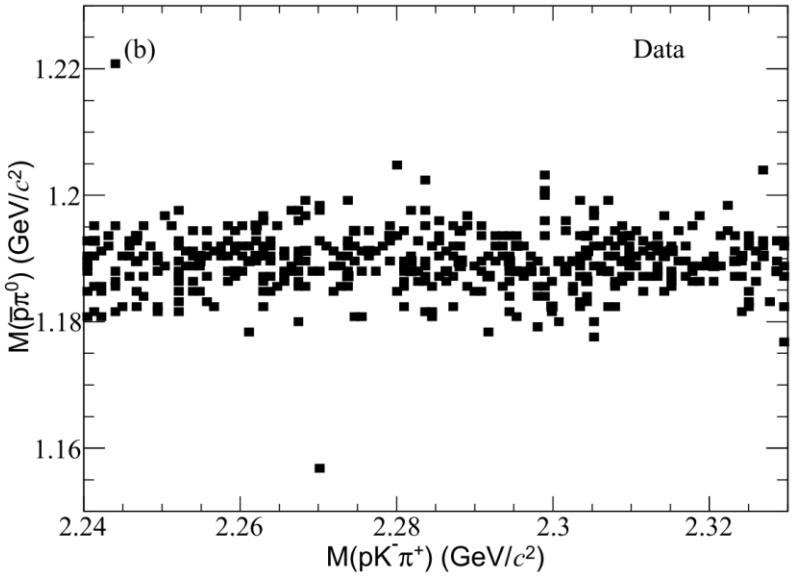
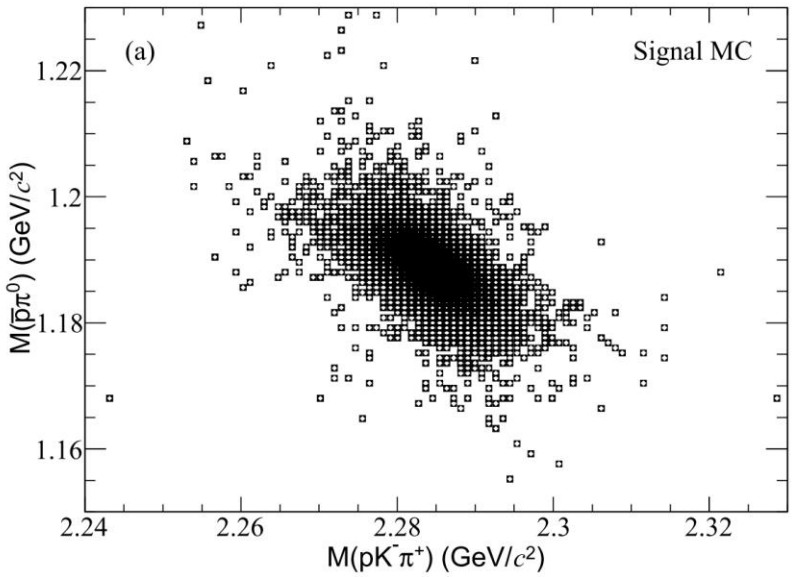
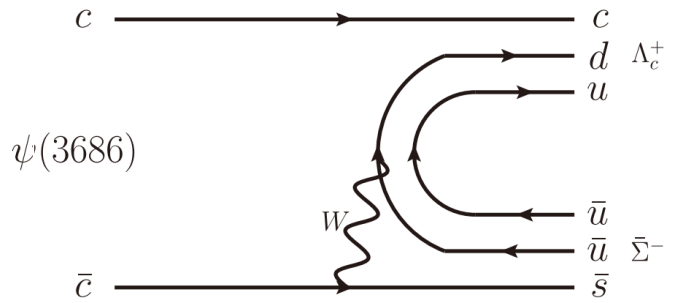
- Summary

Search for $\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^- + c.c.$

- Searches for purely baryonic weak $\psi(3686)$ decays involving Λ_c^+ have not been performed.
- In the SM theory, $\mathcal{B}(\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^- + c.c.)$ should be 10^{-9}~10^{-11}.
- New physics mechanisms beyond the SM may enhance the BF significantly.
- $\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^-, \Lambda_c^+ \to pK^-\pi^+, \bar{\Sigma}^- \to \bar{p}\pi^0$
- Two main backgrounds:
  - $\psi(3686) \to K^*(892)^- p\bar{\Lambda},\ \bar{\Lambda} \to \pi^+\bar{p}$ ⟸ $M(\pi^+\bar{p})$
  - $\psi(3686) \to \bar{K}^{*0}(892)p\bar{\Sigma}^-,\ \bar{K}^{*0}(892) \to \pi^+K^-$ ⟸ $M(K^-\pi^+)$





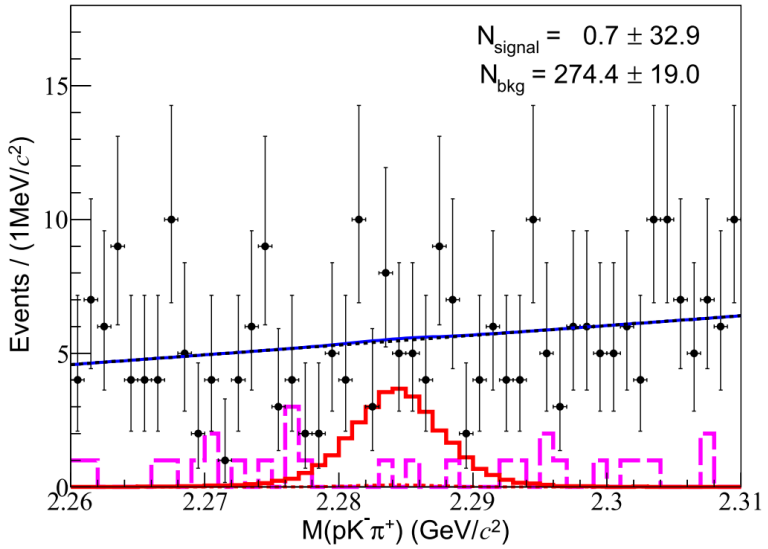


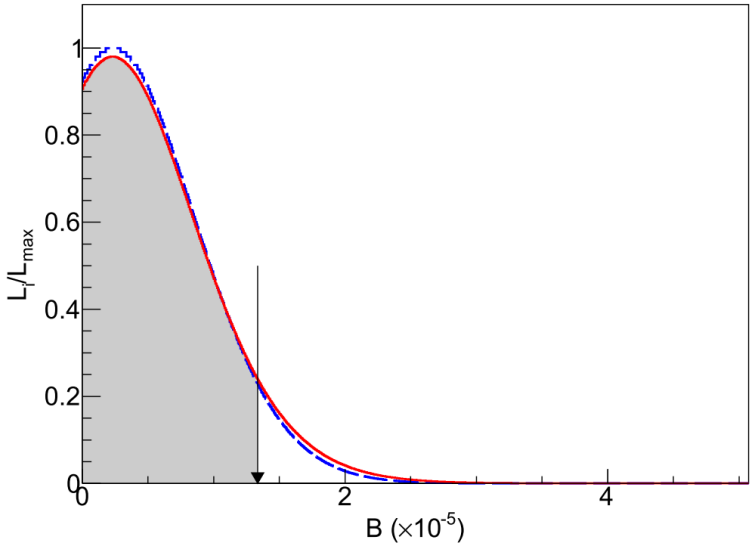
By Luyan Tao et al.

Chin. Phy C, 47, 013002 (2023)

Search for $\psi(3686) \to \Lambda_c^+\bar{\Sigma}^- + c.c.$

- Using $(448.1 \pm 2.9) \times 10^6$ $\psi(3686)$ events from BESIII.
- The signal yield of $\boldsymbol{\psi(3686) \to \Lambda_c^+\bar{\Sigma}^-}$ is extracted from an unbinned maximum likelihood fit to the distribution of $M(pK^-\pi^+)$.
- In the fit, the lineshapes of the signal is modeled by the signal MC and the background is modeled by a first-order Chebyshev polynomial.
- $\boldsymbol{\mathcal{B}(\psi(3686) \to \Lambda_c^+\bar{\Sigma}^- + c.c.) < 1.4 \times 10^{-5}}$ **@90% C.L.**





By Luyan Tao et al.

Chin. Phy. C, 47, 013002 (2023)

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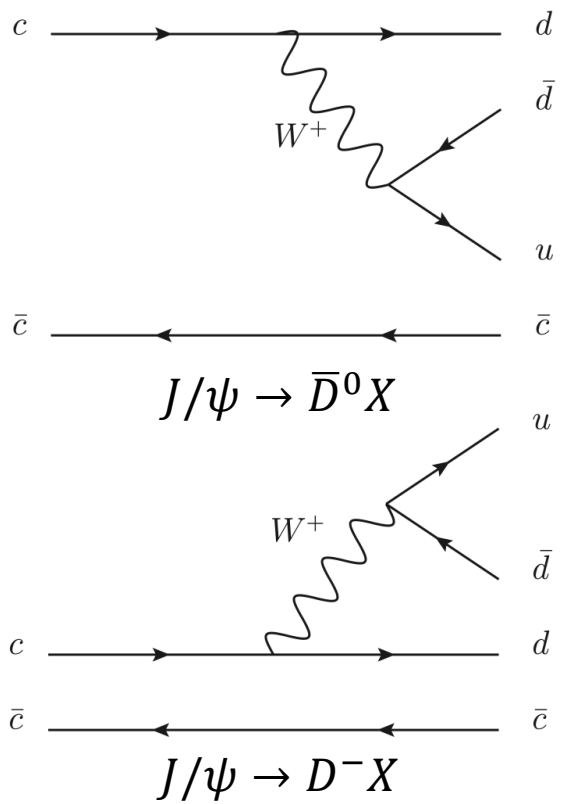
Search for $J/\psi \to \bar{D}^0(D^-)M$

- J/ψ is below $D\bar{D}$ threshold, can only decay to $\bar{D}^0\left(D_{(s)}^{(*)}\right)M$.
- In the SM, $\mathcal{B}(J/\psi \to DM) < 10^{-8}$
  - $\boldsymbol{J/\psi \to \bar{D}^0\pi^0 + c.c.}$
  - $\boldsymbol{J/\psi \to \bar{D}^0\eta + c.c.}$
  - $\boldsymbol{J/\psi \to \bar{D}^0\rho^0 + c.c.}$
  - $\boldsymbol{J/\psi \to D^-\pi^+ + c.c.}$
  - $\boldsymbol{J/\psi \to D^-\rho^+ + c.c.}$
- First measurement of $c \to d$ types for $J/\psi \to PP$ & $J/\psi \to PV$ at BESIII
- $\bar{D}^0 \to K^+e^-\bar{\nu}_e$, $D^- \to K_S^0e^-\bar{\nu}_e$ (with $K_S^0 \to \pi^+\pi^-$)
- $\pi^0/\eta \to \gamma\gamma$, $\rho^0 \to \pi^+\pi^-$, $\rho^+ \to \pi^+\pi^0$
- Using E_{miss}, P_{miss}, U_{miss}, and the recoiling mass of η, π and ρ as requirements.

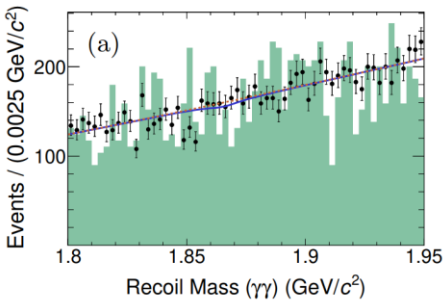
M represents pion, eta, or rho.



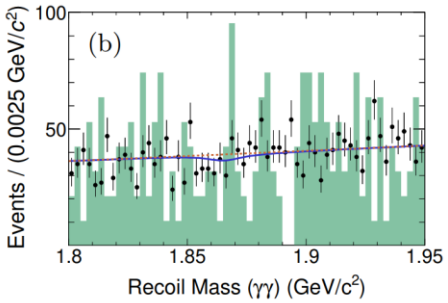
By Chengwei Wang et al. | arXiv:2310.07277

Search for $J/\psi \to \bar{D}^0(D^-)M$

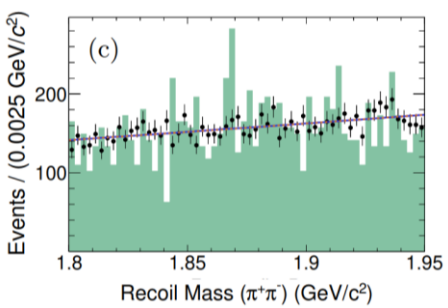
- Fitting the accepted candidates to the recoiling mass spectra for each decays.



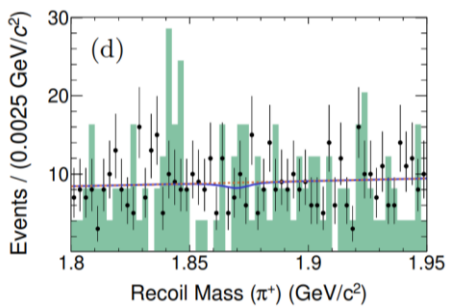
$J/\psi \to \bar{D}^0\pi^0$



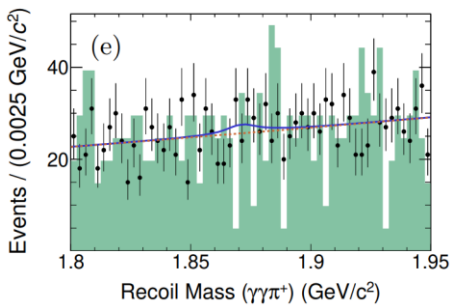
$J/\psi \to \bar{D}^0\eta$



$J/\psi \to \bar{D}^0\rho^0$



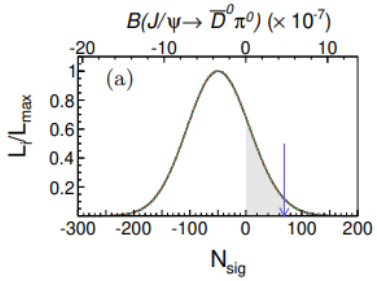
$J/\psi \to D^-\pi^+$

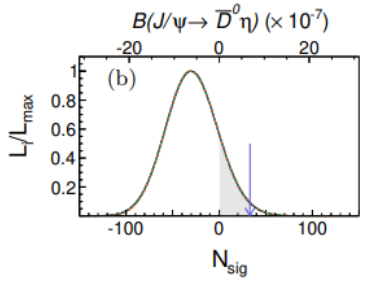


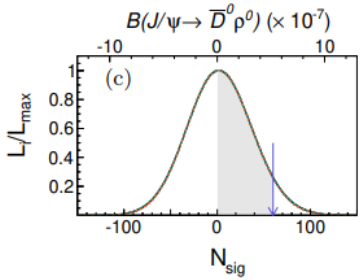
$J/\psi \to D^-\rho^+$

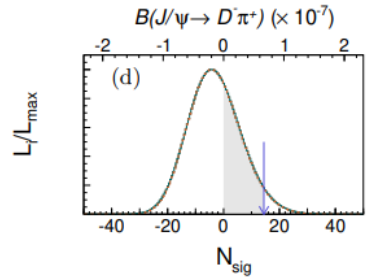
- The Branching fraction at 90% C.L.:

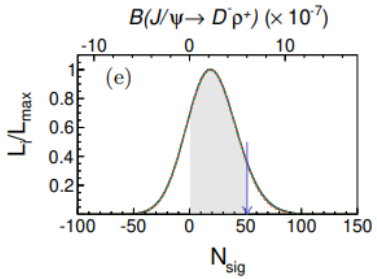
Mode	$\mathcal{B}$(90% C.L.)
$J/\psi \to \bar{D}^0\pi^0$	$< 4.7 \times 10^{-7}$
$J/\psi \to \bar{D}^0\eta$	$< 6.8 \times 10^{-7}$
$J/\psi \to \bar{D}^0\rho^0$	$< 5.2 \times 10^{-7}$
$J/\psi \to D^-\pi^+$	$< 7.0 \times 10^{-8}$
$J/\psi \to D^-\rho^+$	$< 6.0 \times 10^{-7}$











By Chengwei Wang et al. | arXiv:2310.07277

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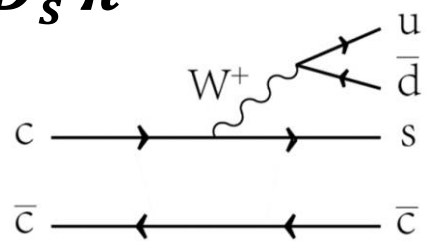
Search for $J/\psi \to D_s(D^0)M$

- In the SM $\mathcal{B}(J/\psi \to DM) < 10^{-8}$, but some new physics models can enhance it to 10^{-6}~10^{-5}
- In previous work, $N_{J/\psi} = 5.8 \times 10^7$ or $N_{J/\psi} = 2.25 \times 10^8$, now we have 10^{10} J/ψ events.

$J/\psi \to D_s^- \rho^+$ & $J/\psi \to D_s^- \pi^+$

- $D_s^- \to \phi e^- \bar{\nu}_e$, $\phi \to K^+K^-$
- $\rho^+ \to \pi^+\pi^0$, $\pi^0 \to \gamma\gamma$

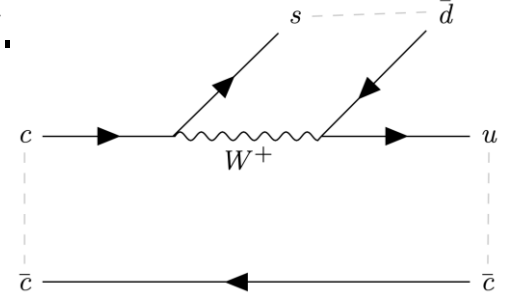


- Event selection: Using $M(D_s)$, $M(\rho)$, $M(\phi)$, E_e/P_e, E_{miss}, P_{miss}, $U_{miss}\cdots$
- Under internal review.

By Yonghua Zhan et al.

$J/\psi \to \bar{D}^0 \bar{K}^{*0} + c.c.$

- $\bar{D}^0 \to K^+ e^- \bar{\nu}_e$
- $\bar{K}^{*0} \to K^- \pi^+$



- Event selection: Using $M^2(K^-\pi^+)$, $M^{recoil^2}_{K^-\pi^+}$, E_e/P_e, E_γ^{tot}, P_{miss}, $U_{miss}\cdots$
- The latest progress was reported on the BESIII workshop.

Year	Number of J/ψ events ($\times 10^6$)	Percentage of partial data (%)	Number of partial data ($\times 10^6$)
2009	224.04	30	67.21
2012	1088.50	10	108.85
2018	4583.41	10	458.34
2019	4191.10	10	419.11
Total	10087		About 1053

By Xiaokang Li et al.

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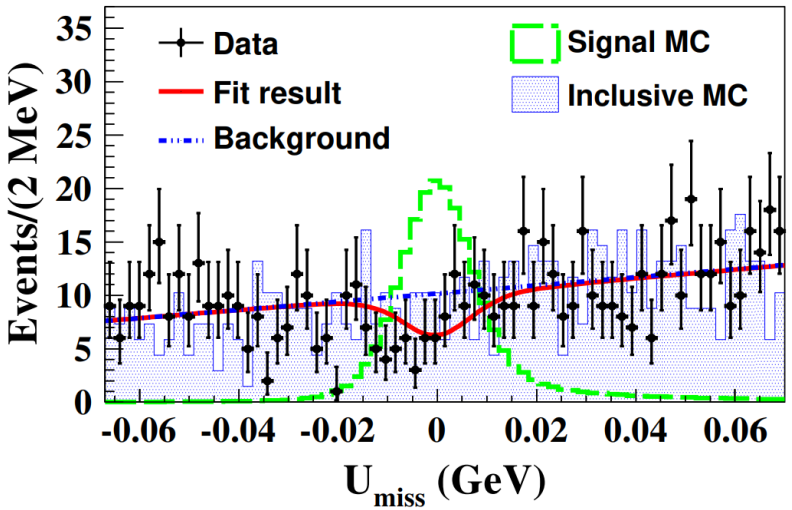
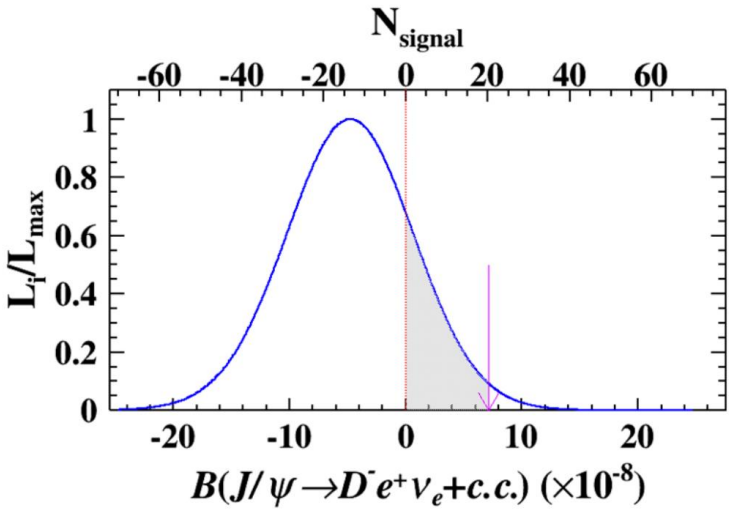
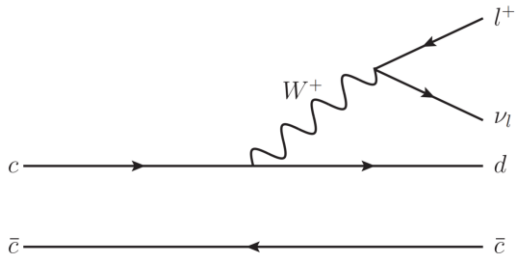
- Charmonium semi-leptonic decays
- FCNC decays
- Summary

Search for $J/\psi \to D^- e^+ \nu_e + c.c.$

- The inclusive branching fraction of J/ψ weak decays to a single charmed meson was predicted to be at the order of 10^{-8} or lower in the SM theory
- In some new physics models, the BF may reach to 10^{-5}.
- $J/\psi \to D^- e^+ \nu_e, D^- \to K^+ K^- \pi^-$
- $(1.0087 \pm 0.0044) \times 10^{10}$ J/ψ events from BESIII
- Using a fit on U_{miss} $(= E_{miss} - |P_{miss}|)$ to extract the signal
- $\mathcal{B}(J/\psi \to D^- e^+ \nu_e + c.c.) < 7.1 \times 10^{-8}$ @90% C.L.
- Puts a stringent constraint on the parameter spaces for different new physics models





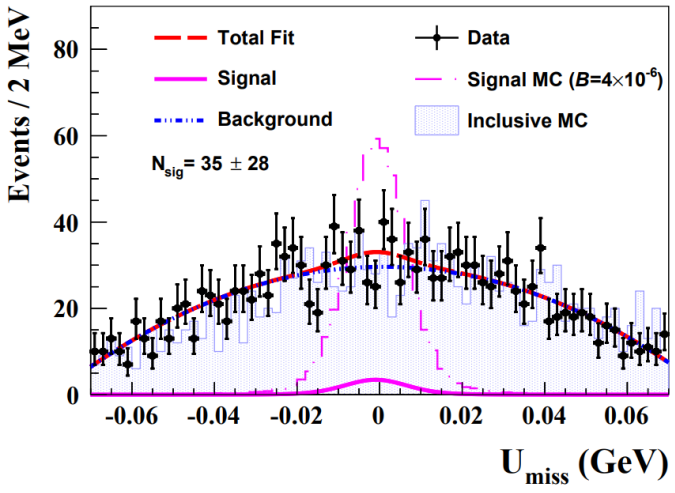


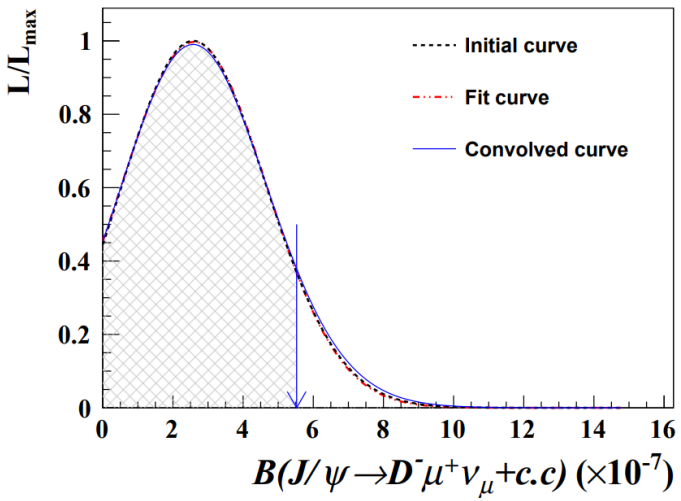
By Chuangxin Lin et al.

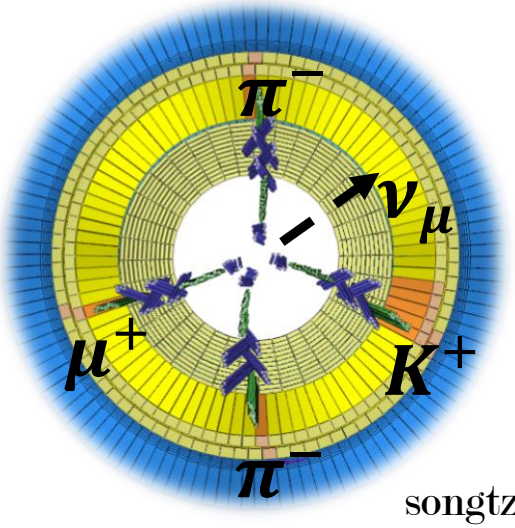
JHEP 06, 157 (2021)

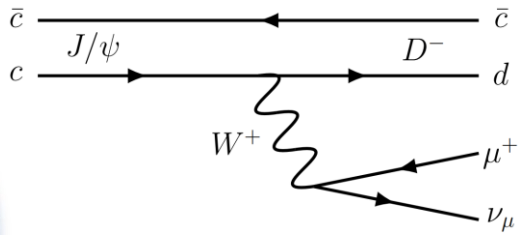
Search for $J/\psi \to D^- \mu^+ \nu_\mu + c.c.$

- The inclusive branching fraction of J/ψ weak decays to a single charmed meson was predicted to be at the order of 10^{-8} or lower in the SM theory
- $(1.0087 \pm 0.0044) \times 10^{10}$ J/ψ events from BESIII
- $J/\psi \to D^- \mu^+ \nu_\mu, D^- \to K^+ K^- \pi^-$
- Using a fit on U_{miss} $(= E_{miss} - |P_{miss}|)$ to extract the signal
- $\mathcal{B}(J/\psi \to D^- \mu^+ \nu_\mu + c.c.) < 5.6 \times 10^{-7}$ @90% C.L.
- The first search of a charmonium weak decay with a muon in the final state.









By Zhijun Li et al.

arXiv:2307.02165

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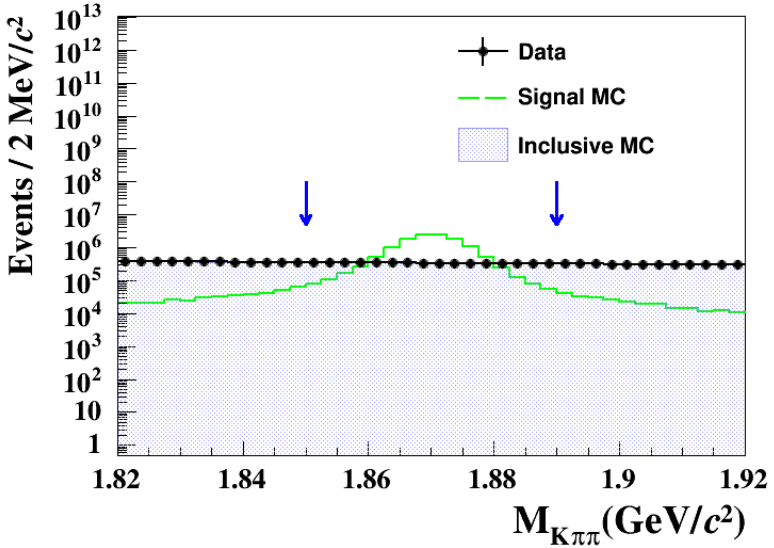
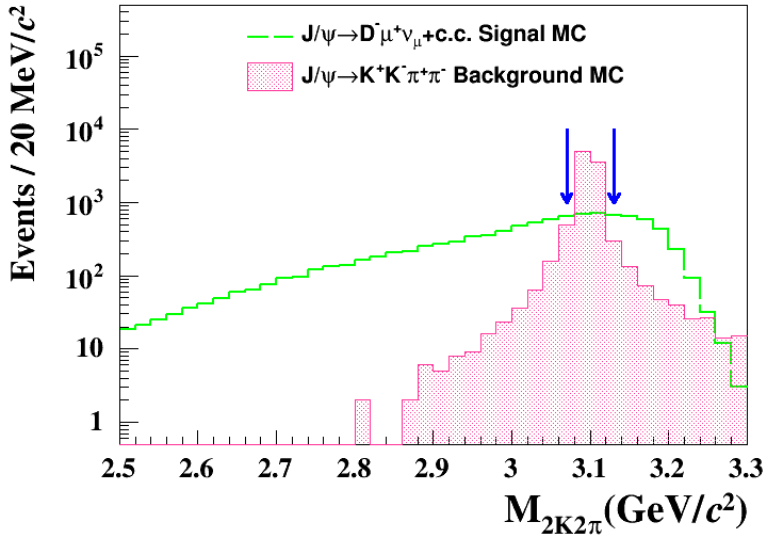
Background analysis method

$J/\psi \to D^- \mu^+ \nu_\mu + c.c.$





- Although the $M(D)$ distribution of signal events has a sharp peaking, we cannot avoid a lot of background events still mixed in.
- But now we have a mature method to veto background events efficiently, which can help us suppress it a lot.

background : $J/\psi \to K^+K^-\pi^+\pi^-$

$\mu^+\nu_\mu$

Identified as : π^+ K^- π^+ μ^-

background : $J/\psi \to K^-K^+\pi^-\pi^+$

$\mu^-\bar{\nu}_\mu$

Identified as : π^- K^+ π^- μ^+

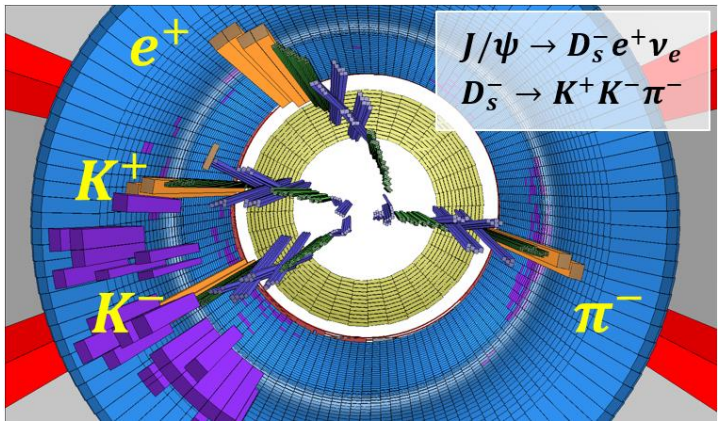
- The key to this approach is to identify the particles that are mis-identified.
- In this way, we can use hadronic decays instead of semi-leptonic decays to reconstruct hadrons.

By Zhijun Li et al.

arXiv:2307.02165

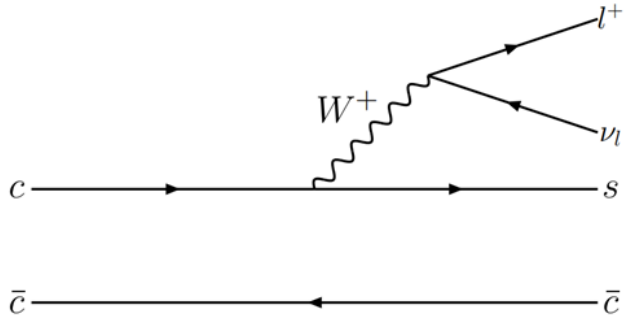
Search for $J/\psi \to D_s^- e^+ \nu_e + c.c.$

- The inclusive branching fraction of J/ψ weak decays to a single charmed meson was predicted to be at the order of 10^{-8} or lower in the SM theory
- 4 tags to reconstruct D_s : (In these decays, $K_S^0 \to \pi^+\pi^-$, $\pi^0 \to \gamma\gamma$)
  - $D_s^- \to K_S^0 K^-$
  - $D_s^- \to K^+K^-\pi^-$
  - $D_s^- \to K^+K^-\pi^-\pi^0$
  - $D_s^- \to K_S^0 K^-\pi^+\pi^-$
- Event selection: Using $M(D_s)$, E_e/P_e, E_γ^{tot}, $|P_e| + |P_{miss}|$, P_{miss}…
- Using a fit on U_{miss} $(= E_{miss} - |P_{miss}|)$ to extract the signal



$\times 10^{-11}$

Decay mode	QCDSR [6]	LFQM [7]	BSW [8]	CCQM [9]	BSM [10]
$J/\psi \to D^- e^+ \nu_e + c.c.$	$0.73^{+0.43}_{-0.22}$	5.1 – 5.7	$6.0^{+0.8}_{-0.7}$	1.71	$2.03^{+0.29}_{-0.25}$
$J/\psi \to D^- \mu^+ \nu_\mu + c.c.$	$0.71^{+0.42}_{-0.22}$	4.7 – 5.5	$5.8^{+0.8}_{-0.6}$	1.66	$1.98^{+0.28}_{-0.24}$
$J/\psi \to D_s^- e^+ \nu_e + c.c.$	18^{+7}_{-5}	53 – 58	$104.0^{+9.0}_{-7.5}$	33	$36.7^{+5.2}_{-4.4}$
$J/\psi \to D_s^- \mu^+ \nu_\mu + c.c.$	17^{+7}_{-5}	55 – 57	$99.3^{+9.5}_{-6.5}$	32	$35.4^{+5.0}_{-4.3}$



By Tianzi Song et al.

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Outline

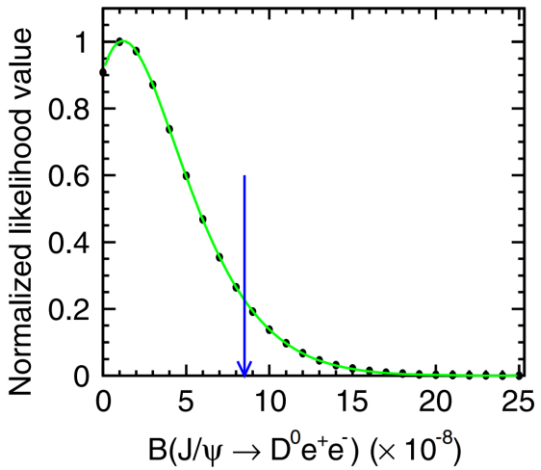
- New physics researches at BESIII
- Charmonium hadronic weak decays
- Charmonium semi-leptonic decays
- FCNC (Flavor Changing Neutral Current) decays
- Summary

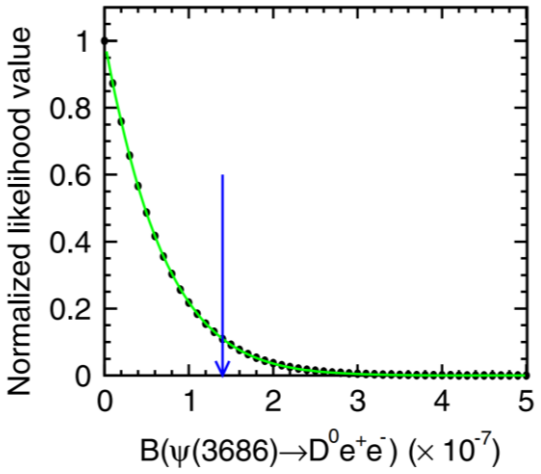
Search for $J/\psi \to D^0 e^+ e^- + c.c.$ & $\psi(3686) \to D^0 e^+ e^- + c.c.$

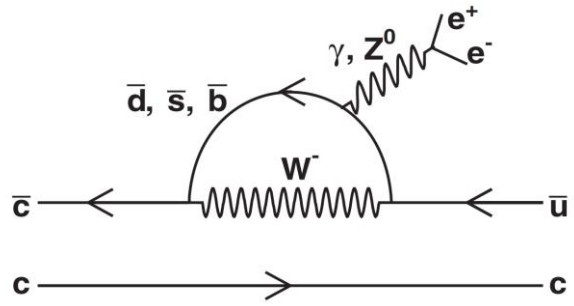
- In the SM model, FCNC is forbidden at the tree level due to the GIM mechanism, it can only occur at the loop level.
- In the SM model, the BF of FCNC process is about 10^{-10}~10^{-13}.
- In new physics models, the BF can be improved by 2~3 orders in magnitude.
- 3 tags to reconstruct D^0: $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$, $D^0 \to K^-\pi^+\pi^-\pi^+$.
- $N_{J/\psi} = 1310.6 \times 10^6$, $N_{\psi(3686)} = 448.1 \times 10^6$.
- Now we are using $N_{J/\psi} = 10087 \times 10^6$ to research $J/\psi \to D^0 e^+ e^- + c.c.$ and $J/\psi \to D^0 \mu^+ \mu^-$.

By Yateng Zhang et al.

Phys. Rev. D 96, 111101(2017)







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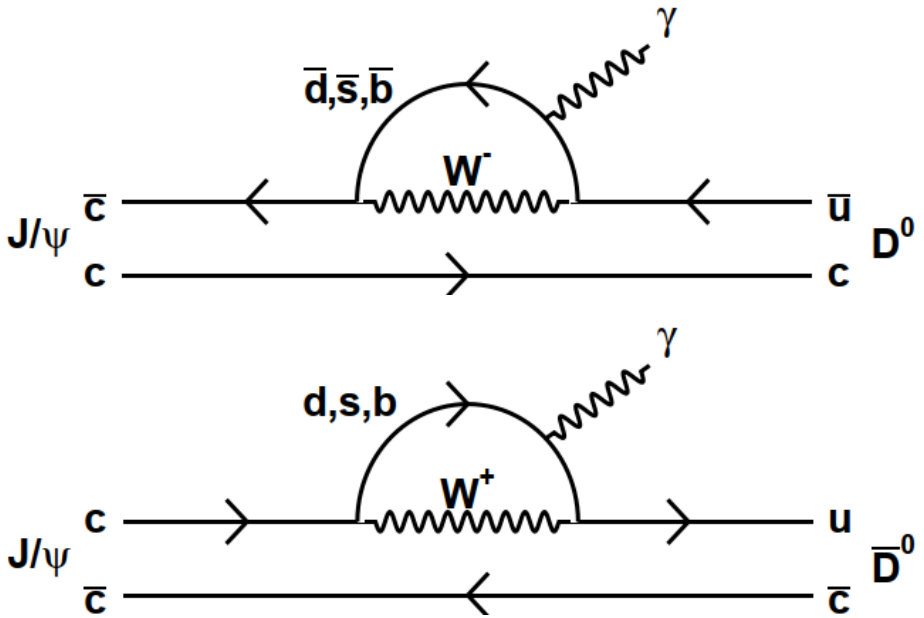
Search for $J/\psi \to \gamma D^0/\bar{D}^0$

By Bo Wang et al.

- In the SM model, the BF of FCNC process is about 10^{-10}~10^{-13}.
- With out decay $\gamma \to e^+e^-$ compared to $J/\psi \to D^0 e^+ e^- + c.c.$.
- In new physics models, the BF can be improved by 2~3 orders in magnitude.
- In the SM model, the BF of FCNC process is about 10^{-10}~10^{-13}.
- In new physics models, the BF can be improved by 2~3 orders in magnitude.
- 3 tags to reconstruct D^0 and $\bar{D}^0$:

D^0	$\bar{D}^0$	Br
$D^0 \to K^-\pi^+$	$\bar{D}^0 \to K^+\pi^-$	$(3.950 \pm 0.030)\%$
$D^0 \to K^-\pi^+\pi^0$	$\bar{D}^0 \to K^+\pi^-\pi^0$	$(14.4 \pm 0.6)\%$
$D^0 \to K^-\pi^+\pi^-\pi^+$	$\bar{D}^0 \to K^+\pi^-\pi^+\pi^-$	$(8.23 \pm 0.14)\%$



- M_D is used to extract the signal shape.
- Under internal review.

Some published articles

Experiment	Decay mode	$N_{J/\psi}$	UL @ 90% CL	year
BESII	$J/\psi \to D_s^- \pi^+ + c.c.$	58×10^6	1.4×10^{-4}	2008
BESII	$J/\psi \to D^0 K^0 + c.c.$	58×10^6	1.7×10^{-4}	2008
BESIII	$J/\psi \to D_s^- \rho^+ + c.c.$	225.3×10^6	1.3×10^{-5}	2014
BESIII	$J/\psi \to D^0 K^{*0} + c.c.$	225.3×10^6	2.5×10^{-6}	2014
BESIII	$J/\psi \to D_s^- e^+ \nu_e + c.c.$	225.3×10^6	1.3×10^{-6}	2014
BESIII	$J/\psi \to D_s^{*-} e^+ \nu_e + c.c.$	225.3×10^6	1.8×10^{-6}	2014
BESIII	$J/\psi \to D^0 e^+ e^- + c.c.$	1310.6×10^6	8.5×10^{-8}	2017
BESIII	$J/\psi \to D^- e^+ \nu_e + c.c.$	10087×10^6	7.1×10^{-8}	2021
BESIII	$J/\psi \to D^- \mu^+ \nu_\mu + c.c.$	10087×10^6	5.6×10^{-7}	2023
BESIII	$J/\psi \to \bar{D}^0 \pi^0 + c.c.$	10087×10^6	4.7×10^{-7}	2023
BESIII	$J/\psi \to \bar{D}^0 \eta + c.c.$	10087×10^6	6.8×10^{-7}	2023
BESIII	$J/\psi \to \bar{D}^0 \rho^0 + c.c.$	10087×10^6	5.2×10^{-7}	2023
BESIII	$J/\psi \to D^- \pi^+ + c.c.$	10087×10^6	7.0×10^{-8}	2023
BESIII	$J/\psi \to D^- \rho^+ + c.c.$	10087×10^6	6.0×10^{-7}	2023
BESIII	$\psi(3686) \to D^0 e^+ e^-$	448.1×10^6	1.4×10^{-7}	2017
BESIII	$\psi(3686) \to \Lambda_c^+ \bar{p} e^+ e^-$	448.1×10^6	1.7×10^{-6}	2018
BESIII	$\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^-$	448.1×10^6	1.4×10^{-5}	2022

Outline

- New physics researches at BESIII
- Charmonium hadronic weak decays
- Charmonium semi-leptonic decays
- FCNC decays
- Summary

Summary

- BESIII performed wide range studies of new physics, with many first searches or best limits.
- In the aspect of charmonium weak decay, the latest publishing result and some ongoing work are shown in this report.
- BESIII has great potentials with unique (and increasing) datasets and analysis techniques in searching for charmonium weak decays and new physics beyond the SM.

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Thank you for listening.

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