



Search for rare charm decays at

BESIII

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On behalf of BESIII Collaboration

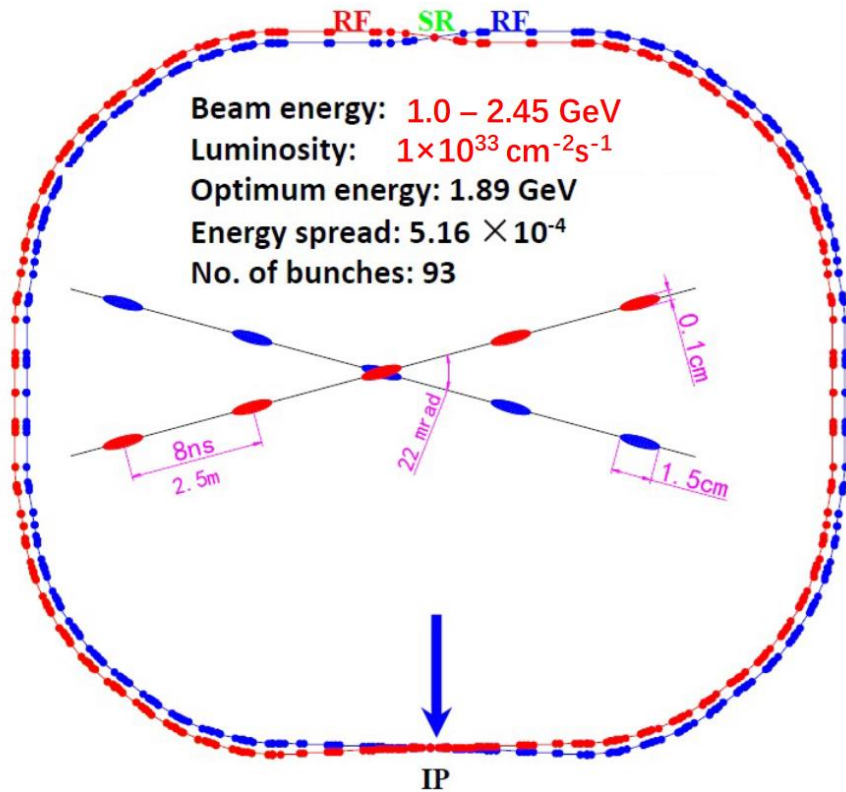




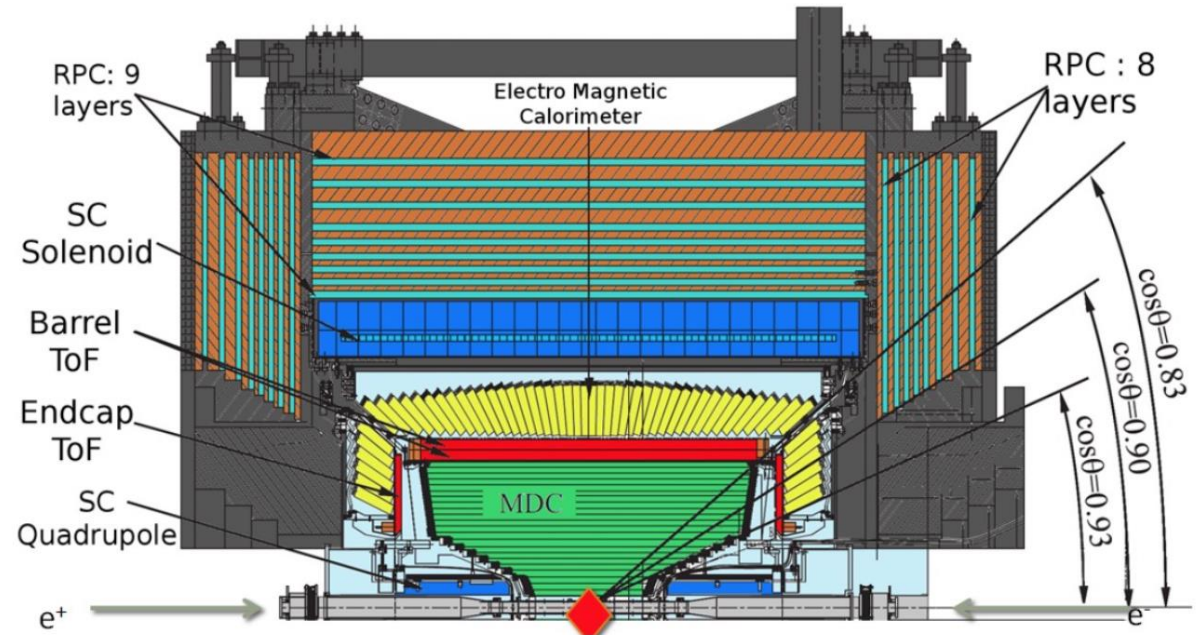
Outline

- ◆ BEPCII and BESIII
- ◆ BESIII data samples
- ◆ Search for charmonium weak decays
- ◆ Search for LFV decays
- ◆ Search for LNV/BNV decays
- ◆ Search for FCNC decays
- ◆ Summary

Beijing Electron Positron Collider II

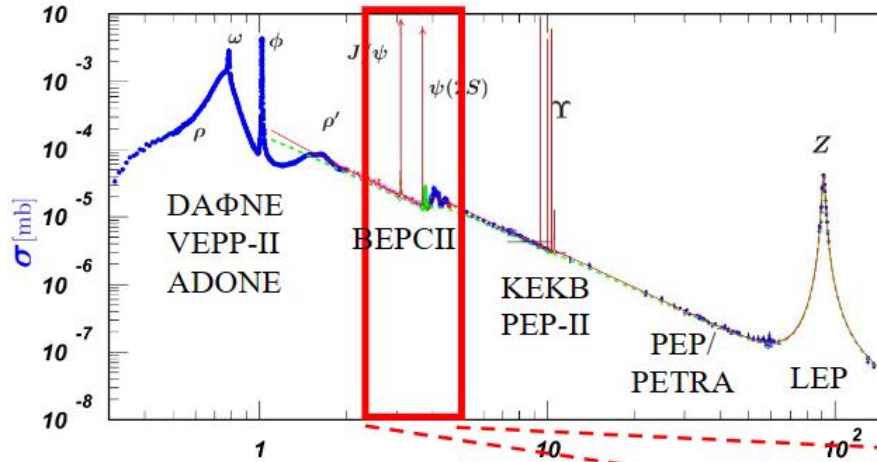


BESIII Detector



- Multilayer drift chamber (MDC)
 - The momentum resolution: 0.5% @ 1GeV/c
 - dE/dx resolution: 6%
- Time-of-flight (TOF) system
 - The time resolution: 68ps(barrel)/60ps(endcap)
- CsI(Tl) Electromagnetic calorimeter (EMC)
 - The energy resolution: 2.5%(barrel)/5.0%(endcap) @ 1GeV
- Supercon-ducting solenoidal magnet (1.0 T magnetic field)
- Muon chamber (MUC) system

BESIII data samples



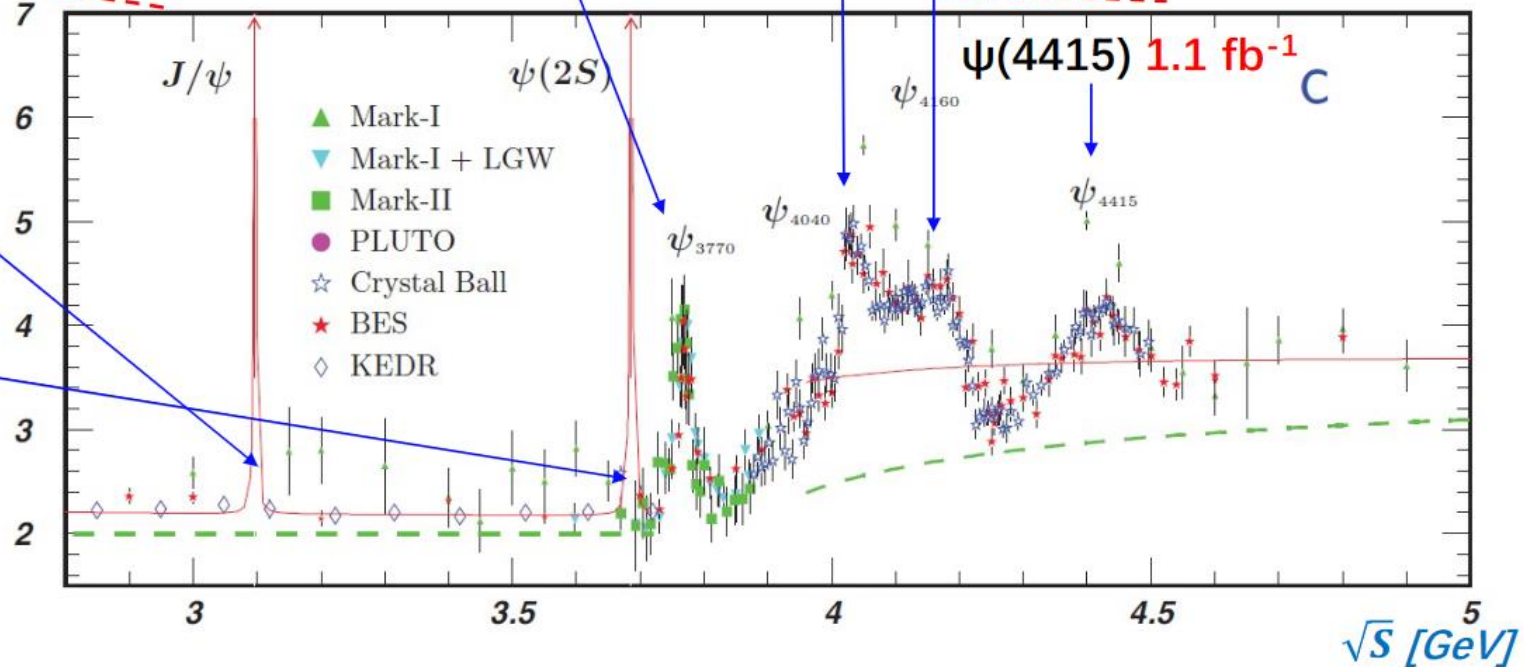
➤ BESIII has collected the largest data samples of J/ψ & $\psi(3686)$ on the threshold in the world, $> 20 \text{ fb}^{-1}$ above 4.0 GeV in total

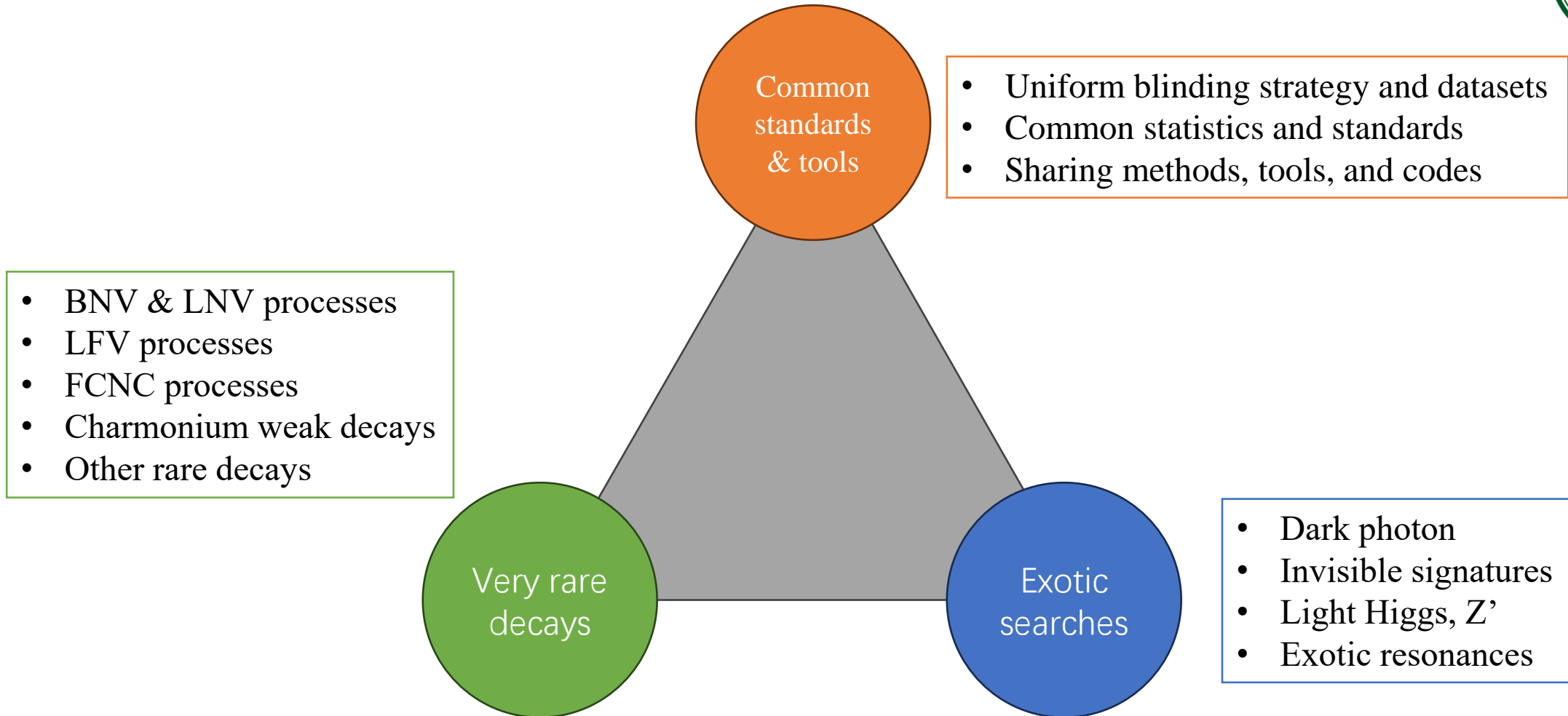
$\psi(3770)$ 2.9 fb^{-1} $\psi(4040)$ 0.5 fb^{-1}
 $\psi(4160)$ 3.2 fb^{-1}

J/ψ 1.0×10^{10}

$\psi(3686)$ 3.0×10^9

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I. New Physics Searches at the BESIII Experiment, S.J. Chen and S. Olsen, Nation Science Review 8, nwab189 (2021), arXiv: 2102.13290

II. New Physics Program of BES, D.Y. Wang, in “30 Years of BES Physics”

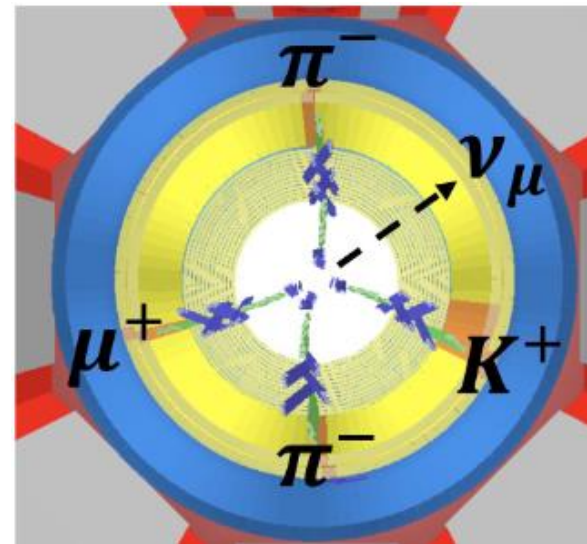
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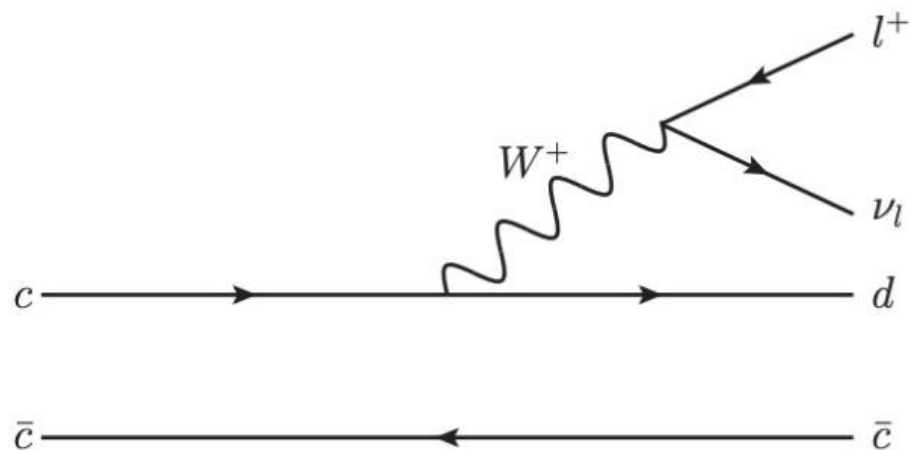
Search for charmonium weak decays at BESIII



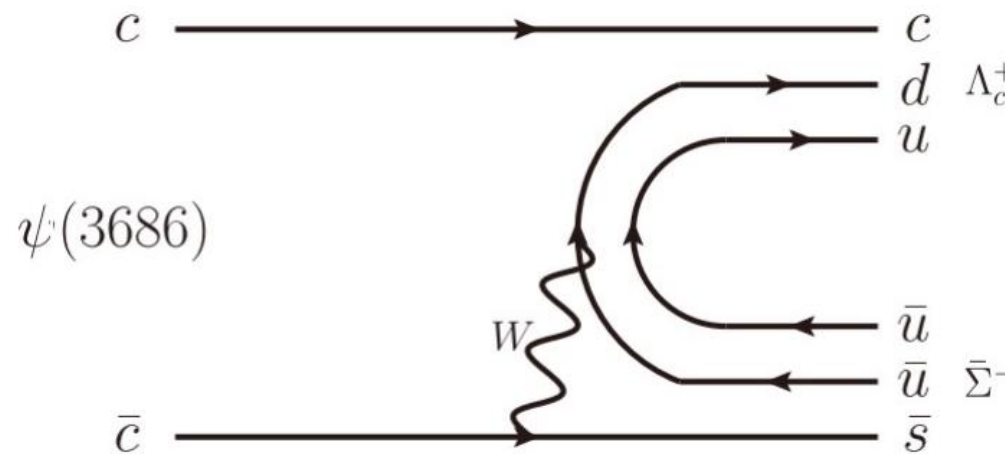
- Search for the charmonium weak decay $J/\psi \rightarrow D^- e^+ \nu_e$
- Search for the charmonium semi-muonic decay $J/\psi \rightarrow D^- \mu^+ \nu_\mu$
- Search for the charmonium weak decay $\psi(3686) \rightarrow \Lambda_c^+ \bar{\Sigma}^-$



(a) Event display plots of $J/\psi \rightarrow D^- \mu^+ \nu_\mu$



(b) The Feynman diagram of $J/\psi \rightarrow D^- l^+ \nu$



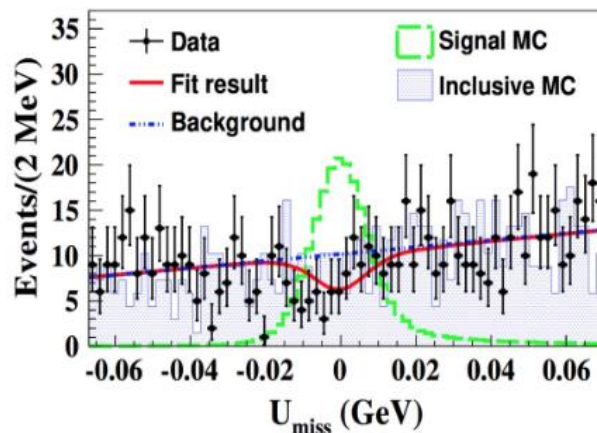
(c) The Feynman diagram of $\psi(3686) \rightarrow \Lambda_c^+ \bar{\Sigma}^-$

Search for decay $J/\psi \rightarrow D^- e^+ \nu_e / D^- \mu^+ \nu_\mu$

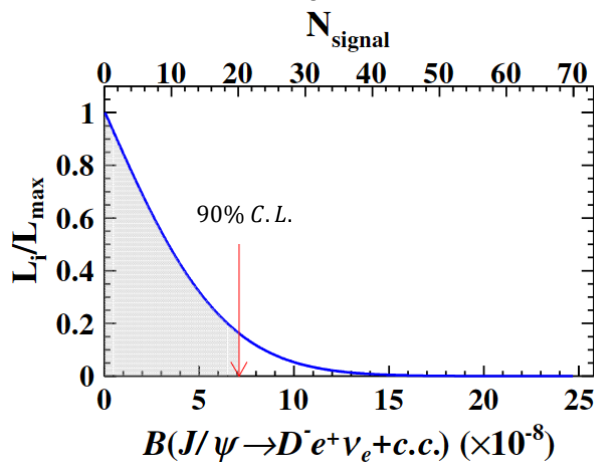
$J/\psi \rightarrow D^- e^+ \nu_e$
JHEP 06,157(2021)



- 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.
- Using $(1.0087 \pm 0.0044) \times 10^{10} J/\psi$ events.
- $J/\psi \rightarrow D^- l^+ \nu, D^- \rightarrow K^+ \pi^- \pi^-$
- Using a fit on $U_{miss}(= E_{miss} - c|P_{miss}|)$ to extract the signal.



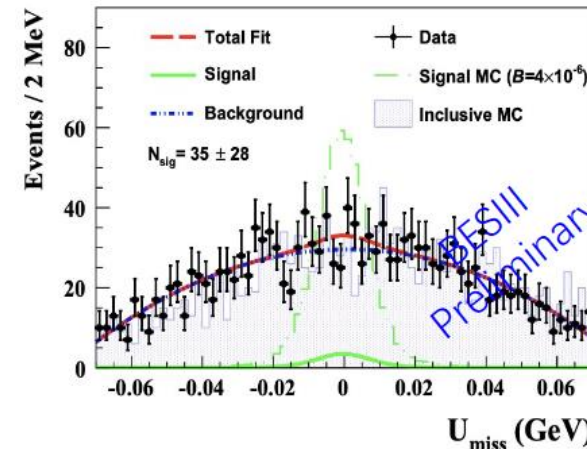
(a) Fitting in full data



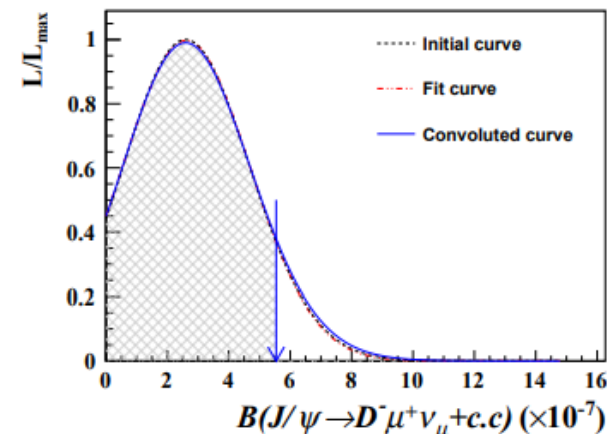
(b) Upper limit in full data

- $B(J/\psi \rightarrow D^- e^+ \nu_e) < 7.1 \times 10^{-8}$ @90% C.L.
- Puts a stringent constraint on the parameter spaces for different new physics models predicting BF's at the order of 10^{-5} .

$J/\psi \rightarrow D^- \mu^+ \nu_\mu$



(c) Fitting in full data

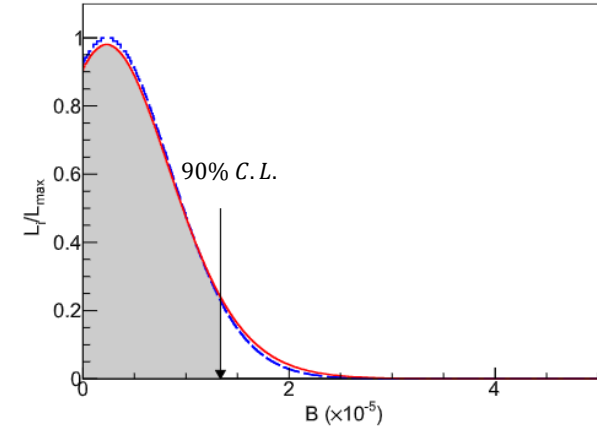
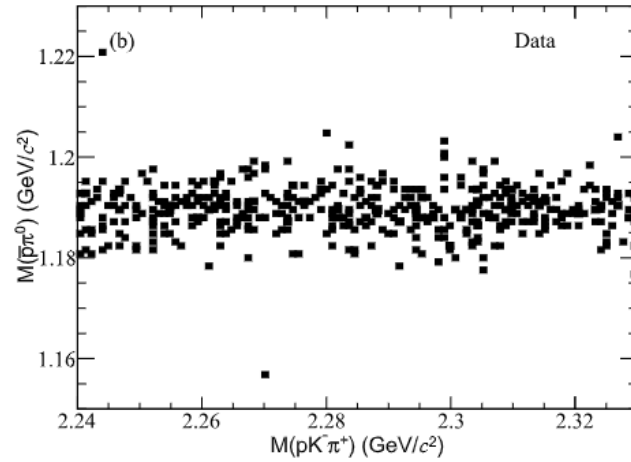
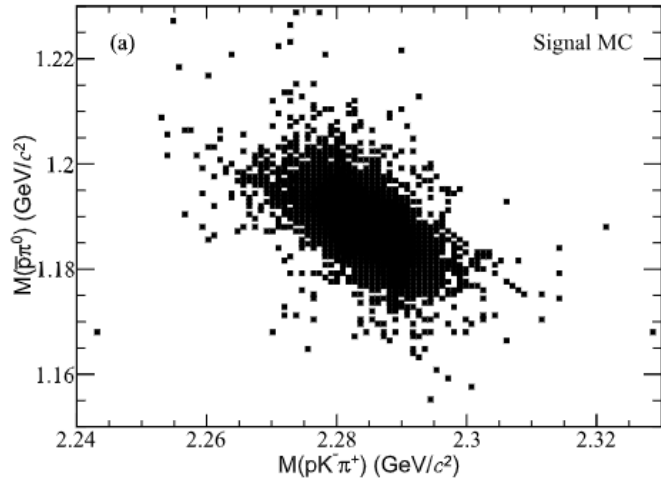


(d) Upper limit in full data

- $B(J/\psi \rightarrow D^- \mu^+ \nu_\mu) < 5.6 \times 10^{-7}$ @90% C.L.
- The first search of a charmonium weak decay with a muon in the final state.

Search for decay $\psi(3686) \rightarrow \Lambda_c^+ \bar{\Sigma}^-$

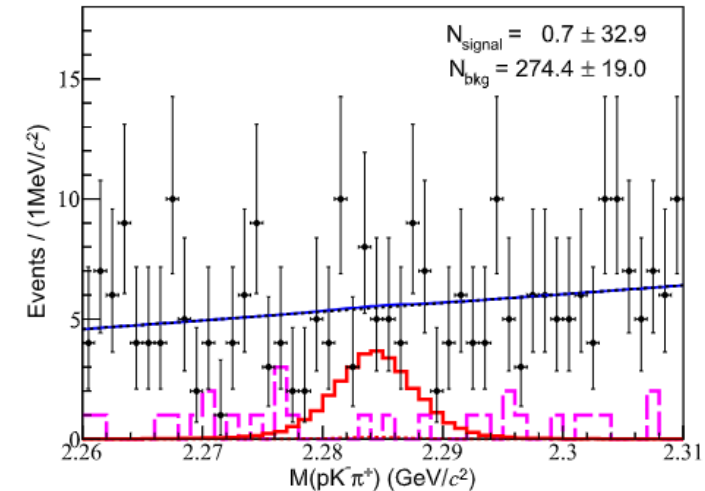
$\psi(3686) \rightarrow \Lambda_c^+ \bar{\Sigma}^-$
Chin Phy C, 47, 013002 (2023)



(c) Upper limit in full data

(a)(b) Distribution of $M(\bar{p}\pi^0)$ versus $M(pK^-\pi^+)$ for the accepted candidate events in the signal MC sample and data.

- Study the low energy QCD effects that determine the hadronic transition matrix elements and find evidence of new physics in the process.
- Using $(448.1 \pm 2.9) \times 10^6$ $\psi(3686)$ events.
- $\psi(3686) \rightarrow \Lambda_c^+ \bar{\Sigma}^-, \Lambda_c^+ \rightarrow pK^-\pi^+, \bar{\Sigma}^- \rightarrow \bar{p}\pi^0$
- Signal yield is extracted from an unbinned maximum likelihood fit to the $M(pK^-\pi^+)$ distribution.



(d) Fit to the $M(pK^-\pi^+)$ distribution. Points with error bars are data. The red (black) dashed line is the signal (background), and the blue solid curve is the total fit. The pink dashed line is the inclusive MC sample. The red solid curve is the signal shape enlarged by a factor of 100

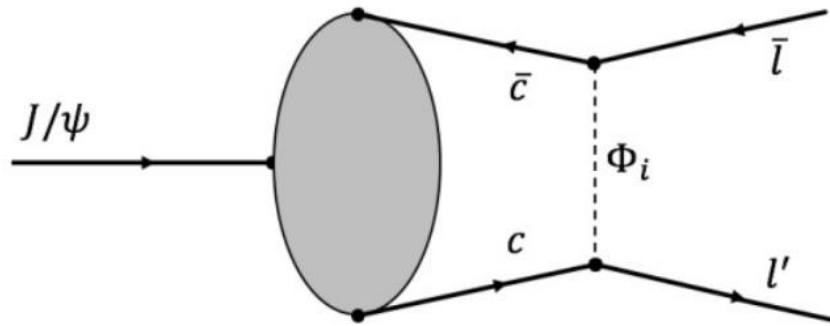
➤ $\mathcal{B}(\psi(3686) \rightarrow \Lambda_c^+ \bar{\Sigma}^-) < 1.4 \times 10^{-5}$ @90% C.L.

Search for charged lepton flavor violating decay

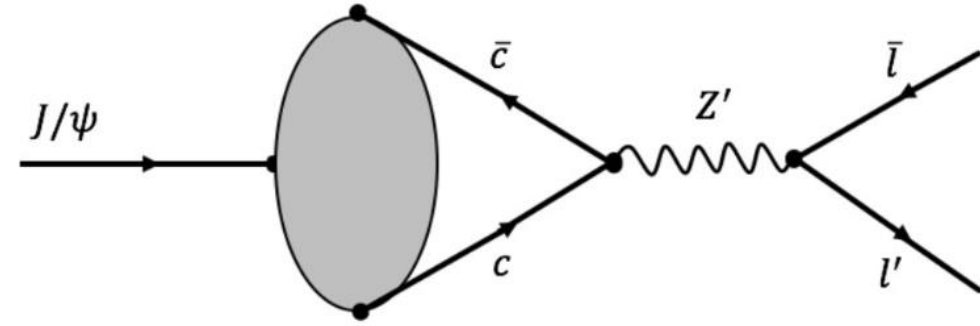


➤ Search for CLFV decay $J/\psi \rightarrow e\tau$

➤ Search for CLFV decay $J/\psi \rightarrow e\mu$



(a) Diagram via leptoquarks



(b) Diagram via a Z' in TC2 models

Diagrams of LFV decay $J/\psi \rightarrow l' \bar{l}$ in models beyond SM.

Phys. Lett. B 496,89 (2000)

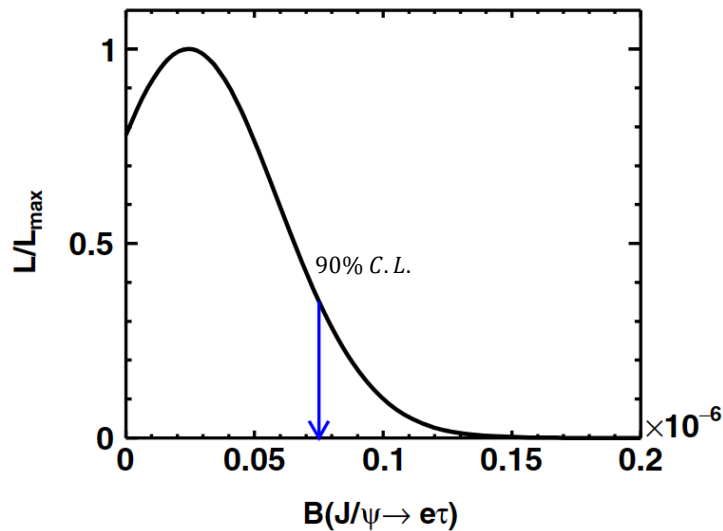
Search for CLFV decay $J/\psi \rightarrow e\tau$



- New physics model predicting $\mathcal{B}(J/\psi \rightarrow e\tau)$ to $10^{-16} \sim 10^{-9}$
- $J/\psi \rightarrow e\tau, \tau \rightarrow \pi\pi^0\nu$
- $U_{miss} = E_{miss} - c|\vec{P}_{miss}|$
- $\mathcal{B}(J/\psi \rightarrow e\tau) < 7.5 \times 10^{-8}$ @90% C.L.
- The first submitted paper based on full 10 billion J/ψ events of BESIII.
- This improves the previous published limits by more than two orders of magnitude and can be used to constrain

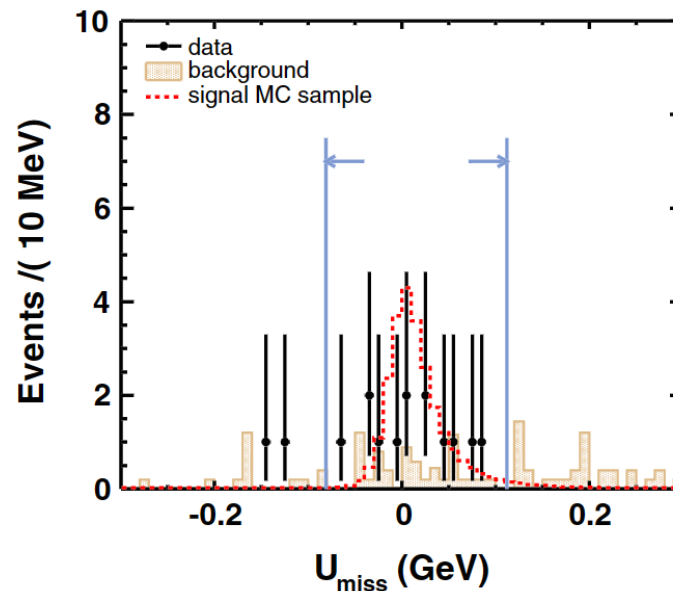
$J/\psi \rightarrow e\tau$
Phys. Rev. D 103,112007 (2021)

new physics parameter spaces.



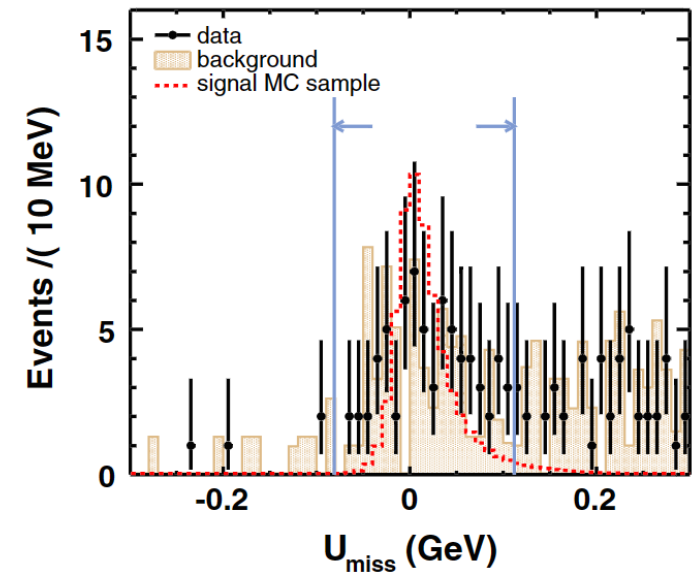
(a) The combined likelihood distribution as a function of the branching fraction of the data samples.

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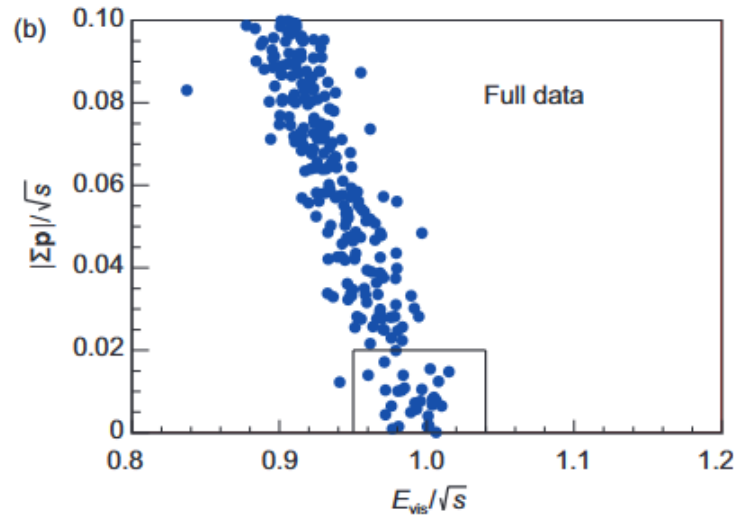
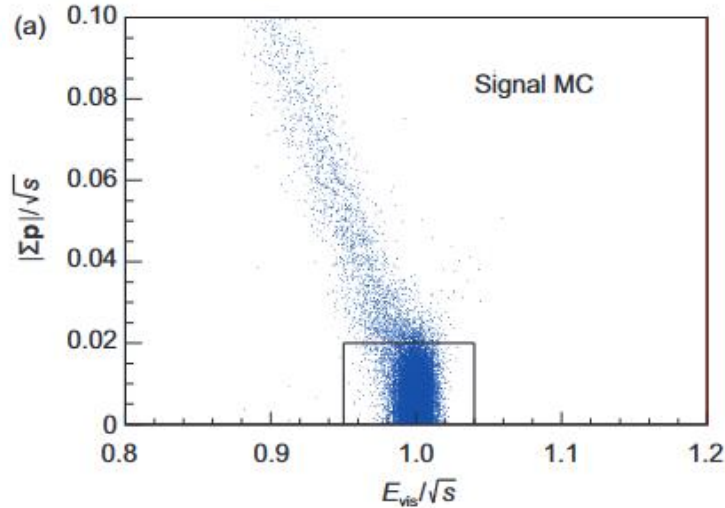
(b) The U_{miss} distribution of data sample I (data collected in 2009 and 2012) and corresponding background.

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(c) The U_{miss} distribution of data sample II (data collected in 2018 and 2019) and corresponding background.

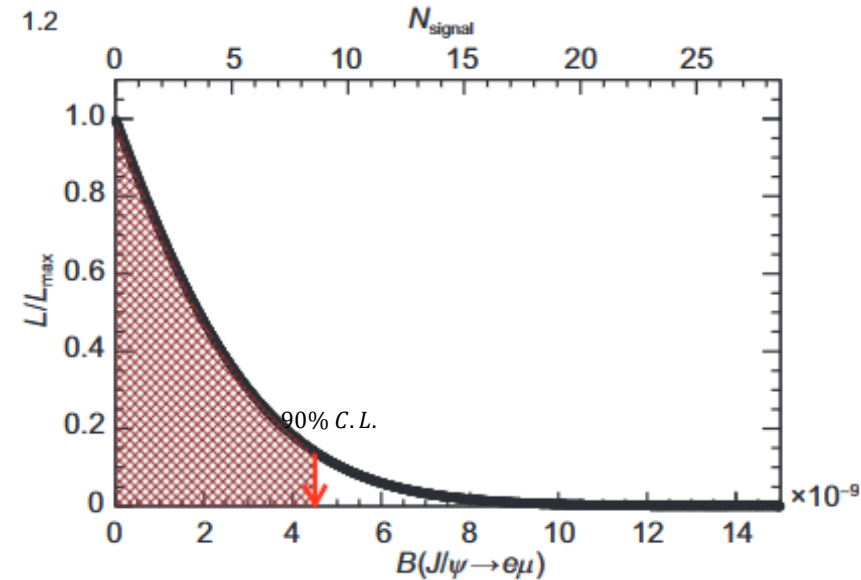
Search for CLFV decay $J/\psi \rightarrow e\mu$



(a)(b) Scatter plots of $|\Sigma p|/\sqrt{s}$ versus E_{vis}/\sqrt{s} for the signal MC sample (a) and the J/ψ full data (b)

$J/\psi \rightarrow e\mu$
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 66 2 (2023)

- New physics model predicting $\mathcal{B}(J/\psi \rightarrow e\mu)$ to $10^{-10} \sim 10^{-8}$
- Using 8.998×10^9 J/ψ events.
- $|\Sigma \vec{p}|$, E_{vis} , and \sqrt{s} are the vector sum of the total momentum of the final states, the total reconstructed energy in one event, and the center-of-mass (c.m.) energy, respectively.



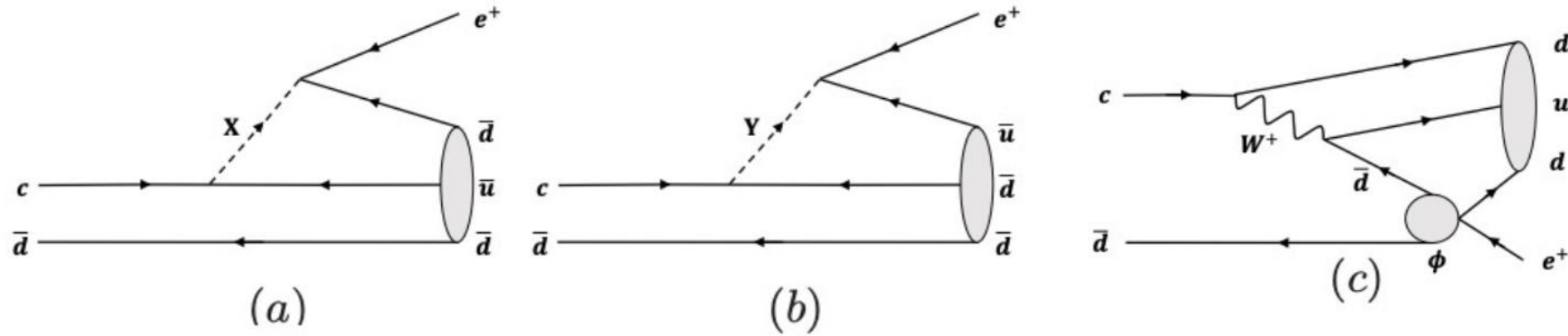
(c) Normalized likelihood distribution as a function of the assumed $\mathcal{B}(J/\psi \rightarrow e\mu)$

- $\mathcal{B}(J/\psi \rightarrow e\mu) < 4.5 \times 10^{-9}$ @90% C.L.
- Improves the previously published limits by a factor of more than 30.
- The most precise result of CLFV search in heavy quarkonium systems.

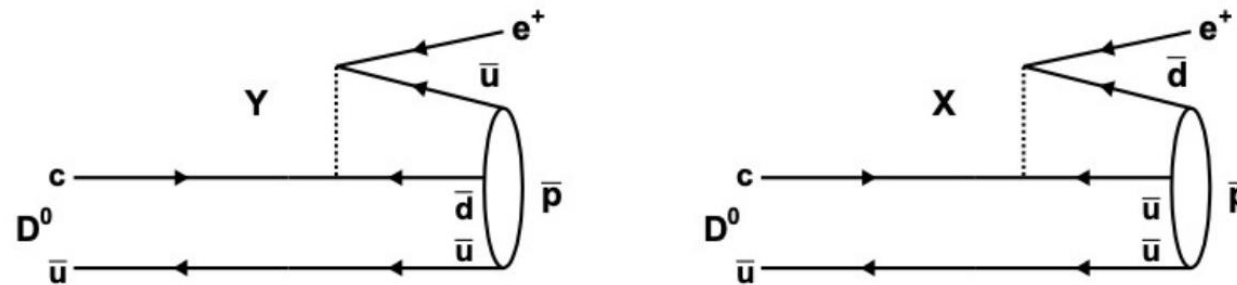
Search for LNV/BNV decays at BESIII



- Search for baryon and lepton number violation decay $D \rightarrow ne$
- Search for baryon and lepton number violation decay $D^0 \rightarrow pe$



Feynman diagrams for $D^+ \rightarrow \bar{n}e^+$ with heavy gauge bosons X (a) and Y (b), and $D^+ \rightarrow ne^+$ with elementary scalar fields ϕ (c).



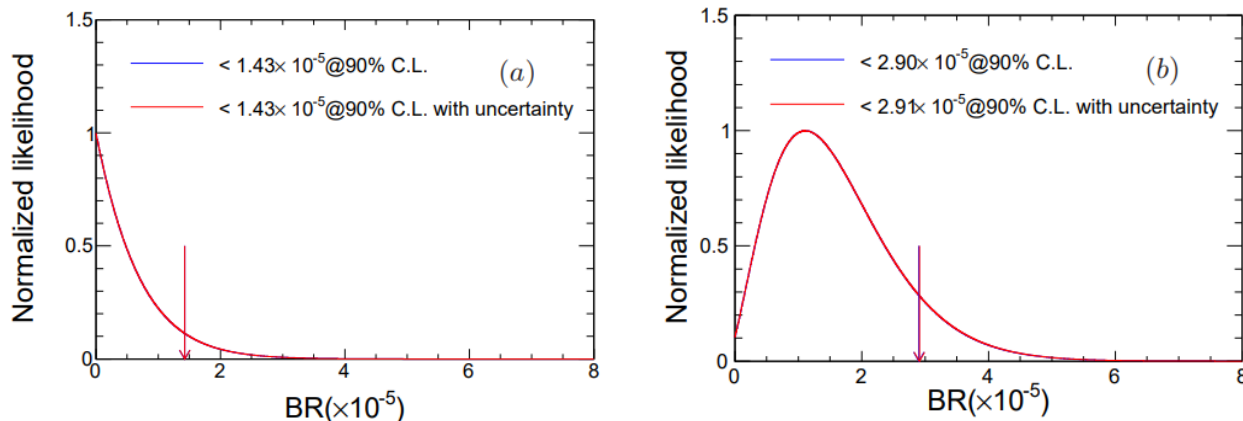
(d) Feynman diagrams of $D^0 \rightarrow \bar{p}e^+$ based on a leptoquark scenario.



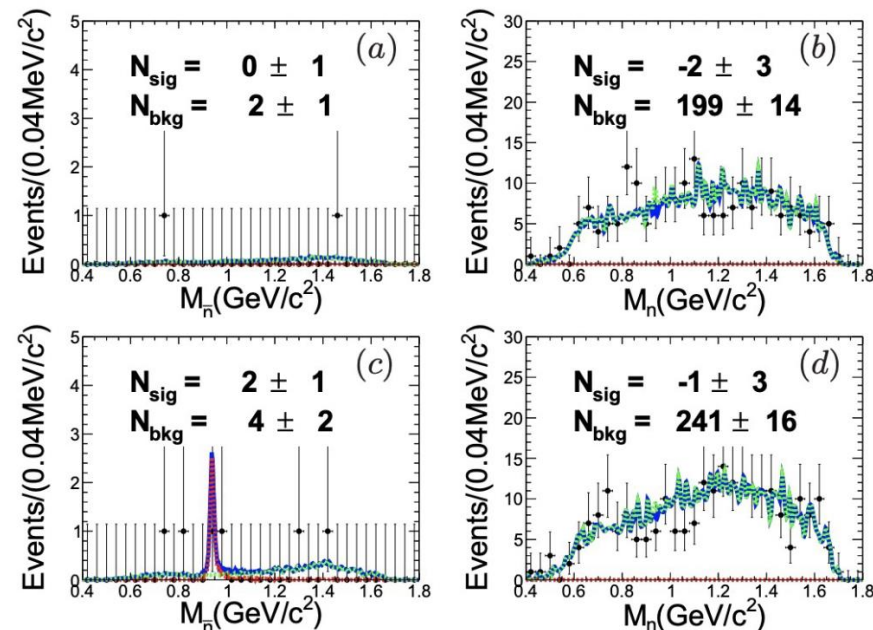
- Excess of baryons over antibaryons in the Universe \rightarrow BNV processes exist, BNV is allowed in GUTs and some SM extensions.
- Using data sample corresponding to an integrated luminosity of $2.93 fb^{-1}$ collected with the BESIII detector at a center-of-mass energy of 3.773 GeV
- \bar{n}, n are regarded as missing particle with momentum & mass inferred from beam condition.

➤ $B(D^+ \rightarrow e^+ \bar{n}) < 1.43 \times 10^{-5}$ @90% C.L.

$B(D^+ \rightarrow ne^+) < 2.92 \times 10^{-5}$ @90% C.L.



The likelihood distribution versus branching fraction for the processes (a) $\Delta|B - L| = 0$ and (b) $\Delta|B - L| = 2$.



Fit for $M_{n/\bar{n}}$ distributions for processes (a) $D^+ \rightarrow \bar{n}e^+$, (b) $D^- \rightarrow ne^-$, (c) $D^- \rightarrow \bar{n}e^-$ and (d) $D^+ \rightarrow ne^+$.

Search for LNV/BNV decay $D^0 \rightarrow pe$

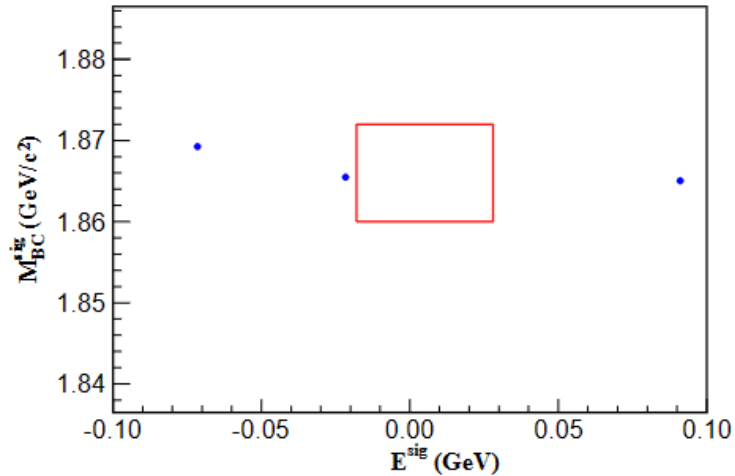


- Excess of baryons over antibaryons in the Universe \rightarrow BNV processes exist, BNV is allowed in GUTs and some SM extensions.
- Using data sample corresponding to an integrated luminosity of $2.93 fb^{-1}$ collected with the BESIII detector at a center-of-mass energy of 3.773 GeV
- With flavor of D determined from tag side,

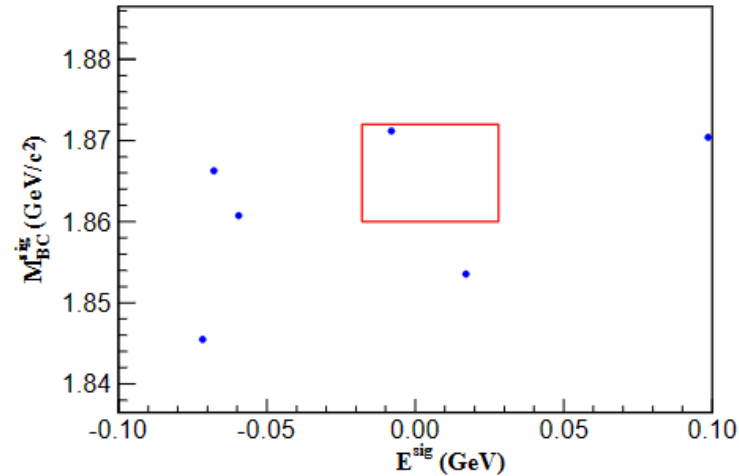
$$B(D^0 \rightarrow e^+ \bar{p}) < 1.2 \times 10^{-6} \text{ @90\% C.L.}$$

$$B(D^0 \rightarrow pe^-) < 2.2 \times 10^{-6} \text{ @90\% C.L.}$$

$D^0 \rightarrow pe$
Phys. Rev. D 105, 032006 (2022)



(a)

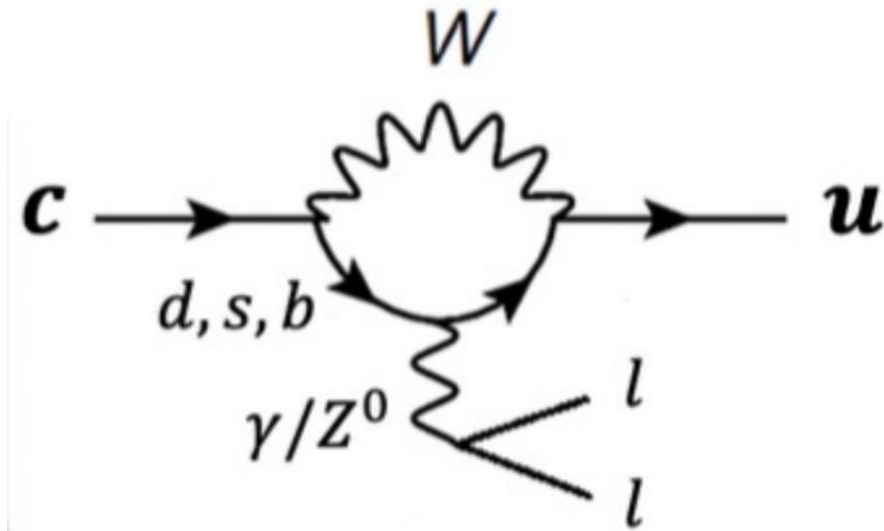


(b)

Distributions of M_{BC}^{sig} vs. ΔE^{sig} of the candidate events for (a) $D^0 \rightarrow \bar{p}e^+$ and (b) $D^0 \rightarrow pe^-$ in data. The red rectangles denote the signal region.



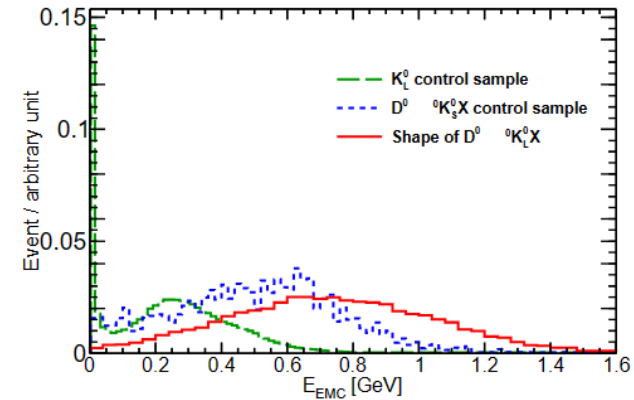
➤ Search for FCNC process $D^0 \rightarrow \pi \nu \bar{\nu}$



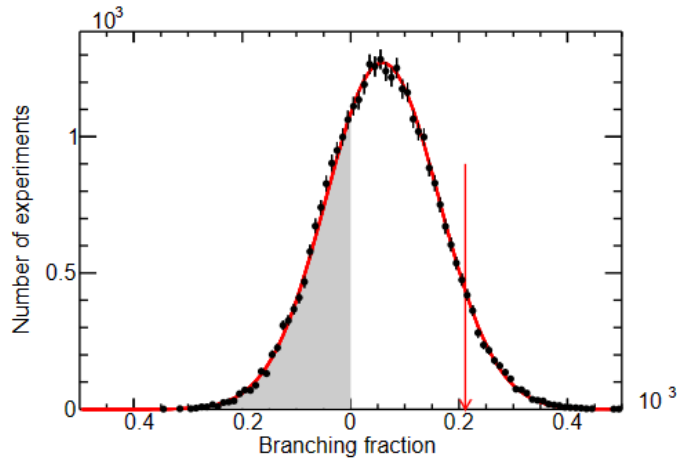


Search for FCNC process $D^0 \rightarrow \pi\nu\bar{\nu}$

- In SM, FCNC is strongly suppressed by the GIM mechanism and can happen only through a loop diagram, to a very small BF $\sim 10^{-9}$, theoretically.
- Using 10.6×10^6 pairs of $D^0\bar{D}^0$ mesons.
- The suppression in charm decays is much stronger than those in B and K systems due to stronger diagram cancellation than the down-type quarks.
- Discriminator: EMC energy not associated with signal and tag decays.



(a) Distributions of E_{EMC} , the summed calorimeter energy unassociated with signal and tag decays.

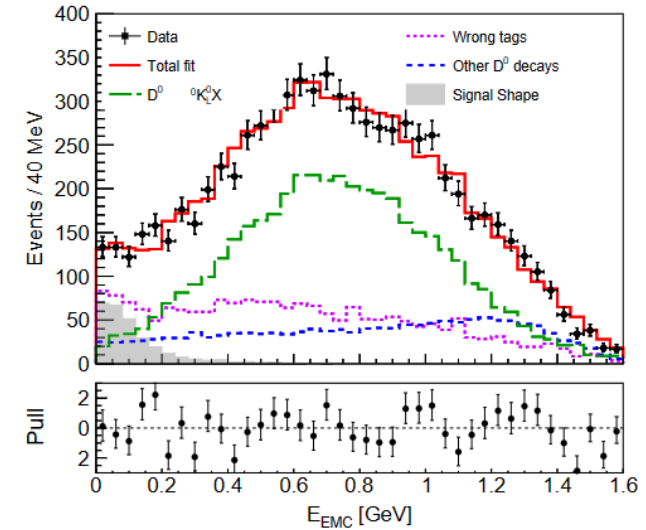


(c) distribution of branching fractions determined from toy samples and a Gaussian fit.

$D^0 \rightarrow \pi\nu\bar{\nu}$
Phys. Rev. D 105, L071102 (2022)

➤ $B(D^0 \rightarrow \pi^0\nu\bar{\nu}) < 2.1 \times 10^{-4}$ @90% C.L.

- Provide a clean probe to search for New Physics in charm sector.
- The first experimental results of search for $c \rightarrow u\nu\bar{\nu}$ processes.



(b) fit to the EMC distribution in data. The bottom panel shows the fit residuals,



- ◆ BESIII performed a wide range study of new physics, with many first searches or best limits
- ◆ The latest search results for rare charm decays in BESIII are reported
- ◆ BESIII has great potential with unique (and increasing) datasets and analysis techniques



Thanks