Search for rare decays at BESIII

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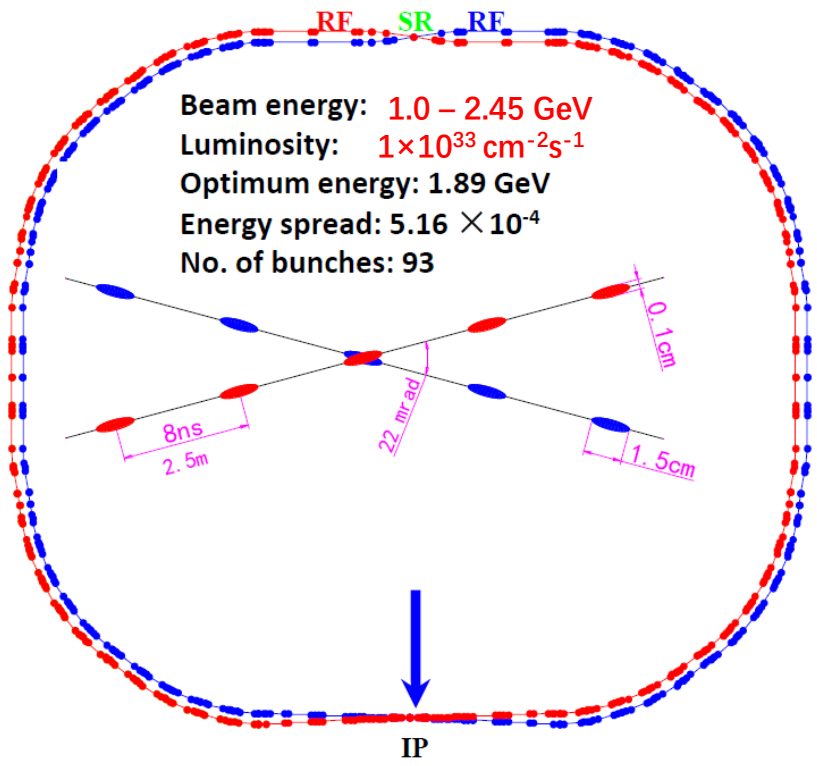
Outline

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

BEPCII and BESIII

Charm Factory

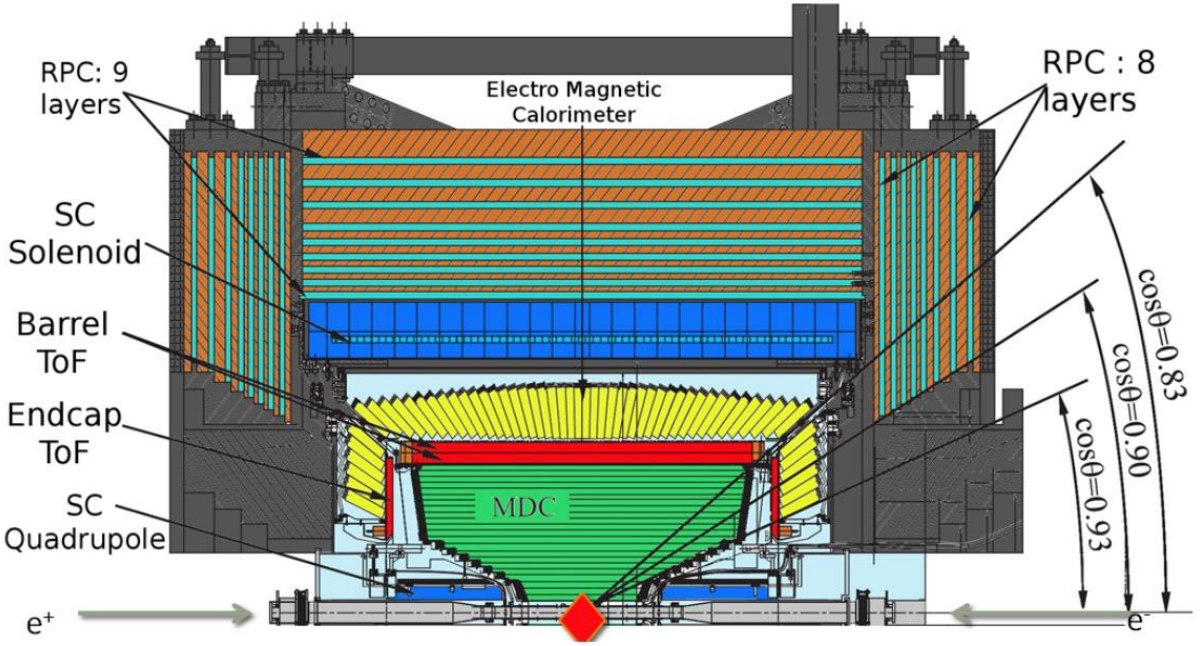
Beijing Electron Positron Collider II



BESIII Detector

MDC: σp=0.5% @ 1GeV/c
dE/dx: 6%

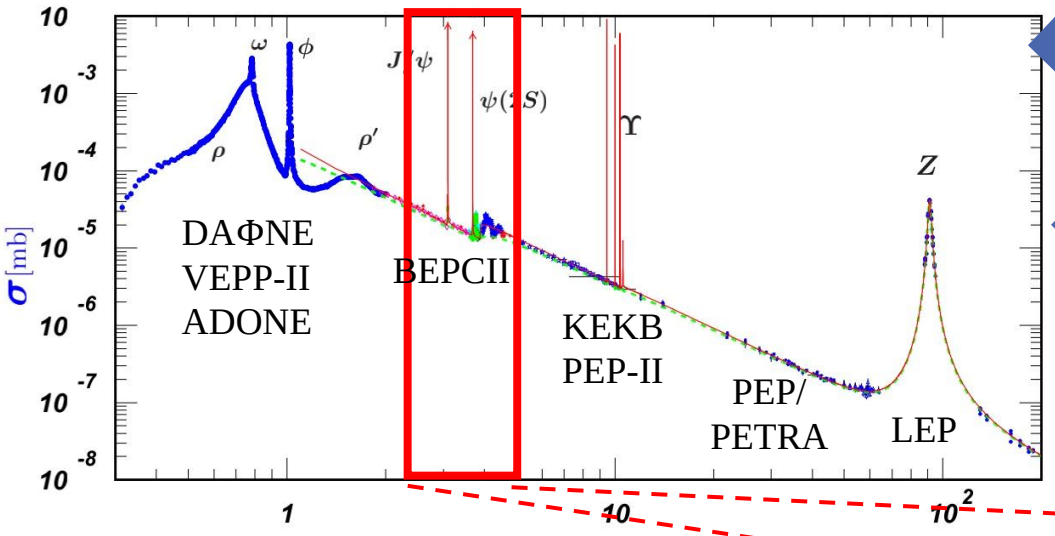
EMC: CsI (Tl) 2.5% (5.0%)
barrel (endcap) @ 1GeV



TOF: σT=68 (60) ps
barrel (endcap)

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

BESIII data samples



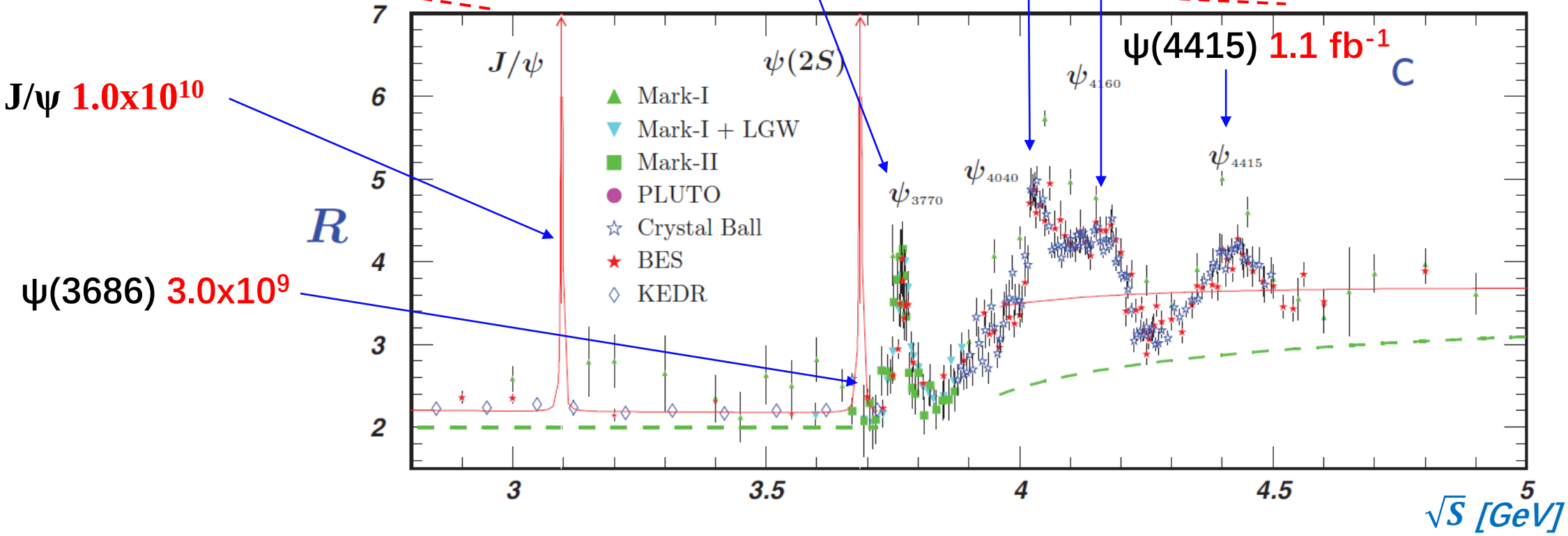
- **BESIII has collected the largest data samples of J/ψ & $\psi(3686)$ on threshold in the world, > 20 fb^{-1} above 4.0 GeV in total**

ψ(3770) 2.9 fb^{-1} ψ(4040) 0.5 fb^{-1}

ψ(4160) 3.2 fb^{-1} ψ(4415) 1.1 fb^{-1}

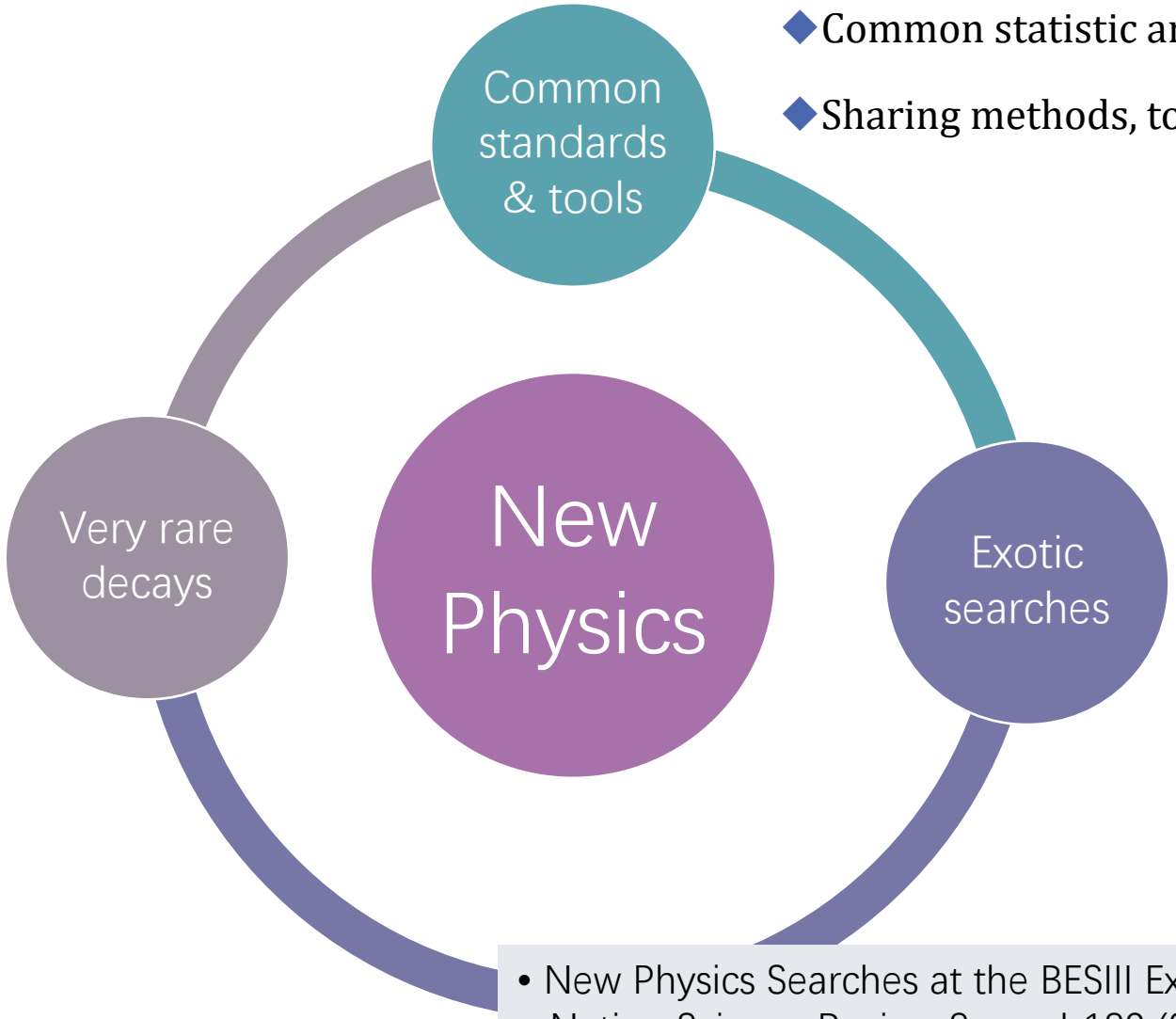
J/ψ 1.0x10^{10}

ψ(3686) 3.0x10^{9}



New Physics Searches at BESIII

- Uniform blinding strategy and datasets
- Common statistic and standards
- Sharing methods, tools and codes



Symmetry

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

Very rare

- FCNC processes
- Charmonium weak decays
- Other rare decays

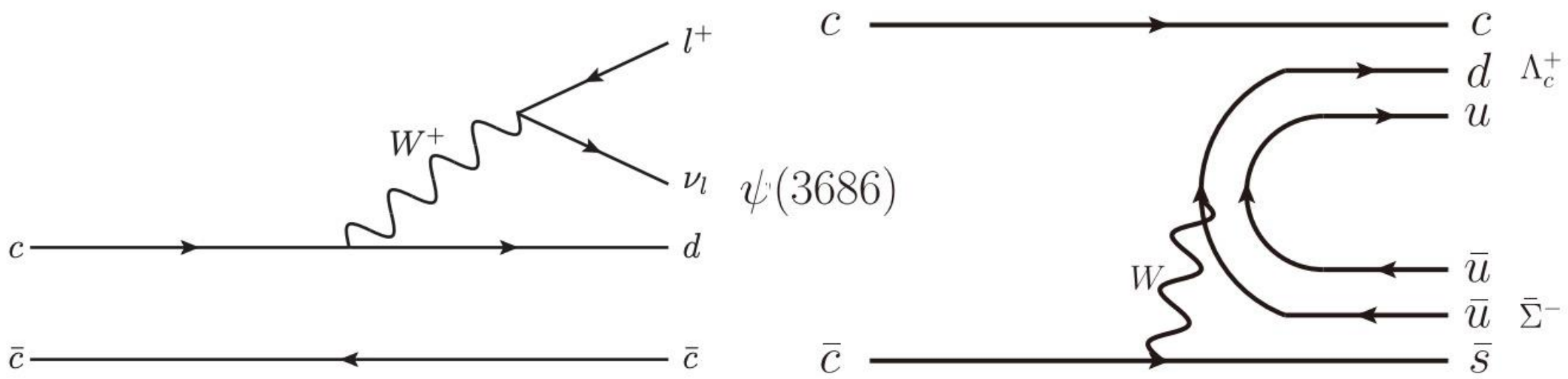
Exotic

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

- New Physics Searches at the BESIII Experiment, S.J. Chen and S. Olsen, Nation Science Review 8, nwab189 (2021), arXiv: 2102.13290
- New Physics Program of BES, D.Y. Wang, in "30 Years of BES Physics"

Search for charmonium weak decays at BESIII

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



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

- 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
- $J/\psi \to D^- l^+ \nu,\ D^- \to K^+ \pi^- \pi^-$
- $\mathcal{B}(J/\psi \to D^- e^+ \nu + c.c.) < 7.1 \times 10^{-8}$ @ 90% C.L.
- Puts a stringent constraint on the parameter spaces for different new physics models predicting BFs at the order of 10^{-5}

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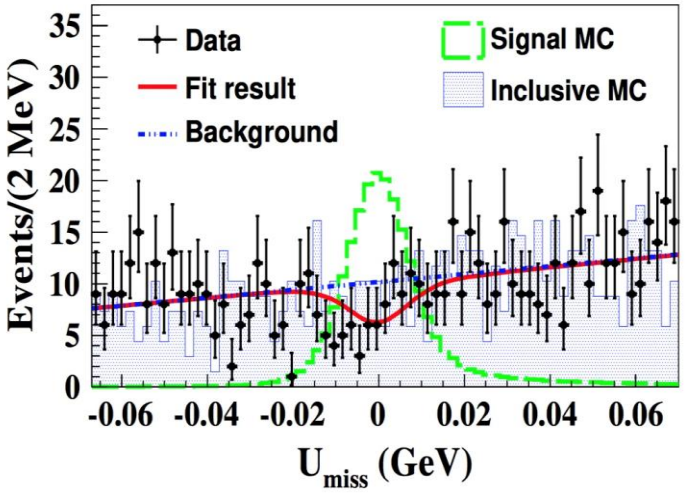
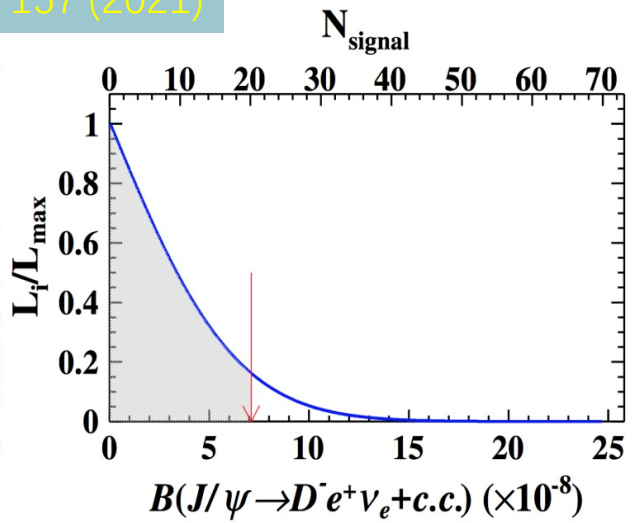
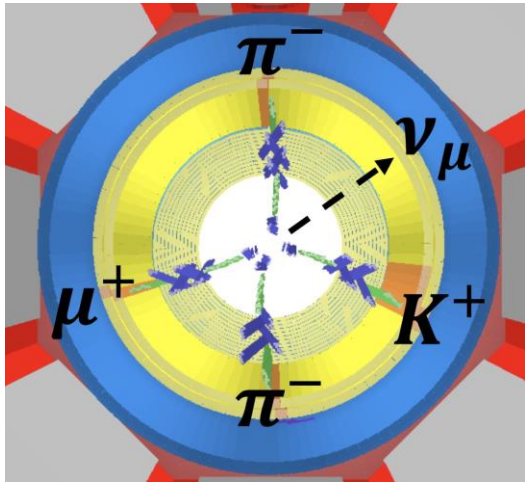
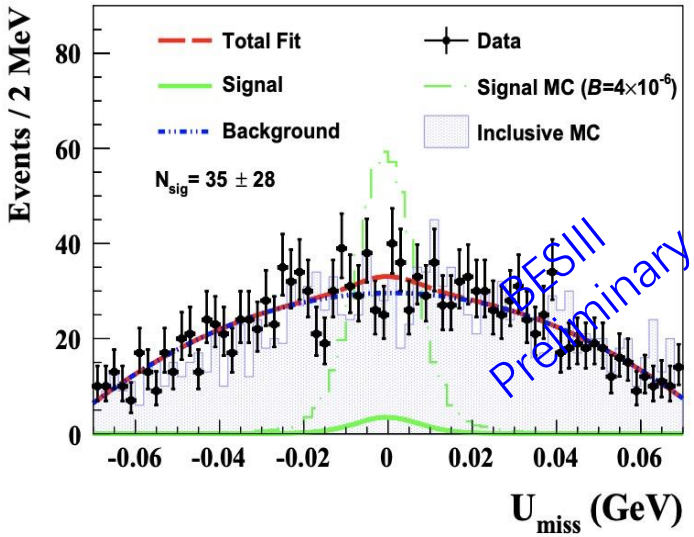
- Using $(1.0087 \pm 0.0044) \times 10^{10}\ J/\psi$ events
- Use a fit on $U_{miss} (= E_{miss} - c|\vec{P}_{miss}|)$ to extract the signal
- $\mathcal{B}(J/\psi \to D^- \mu^+ \nu + c.c.) < 5.6 \times 10^{-7}$ @ 90% C.L.
- The first search of a charmonium weak decay with a muon in the final state.





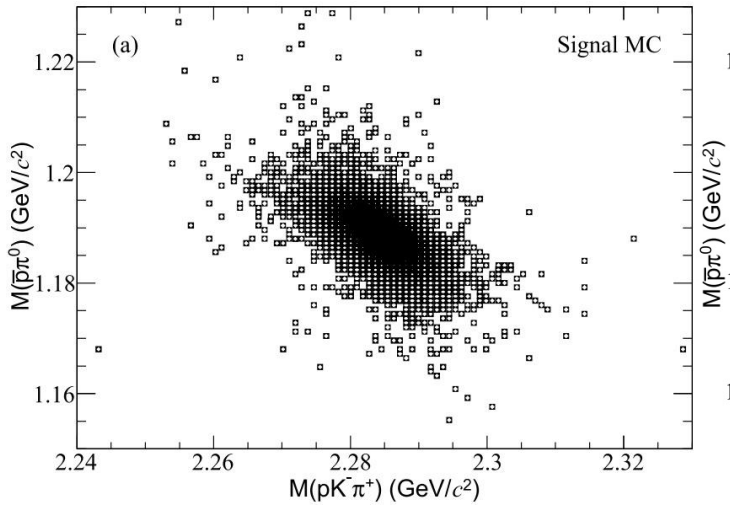


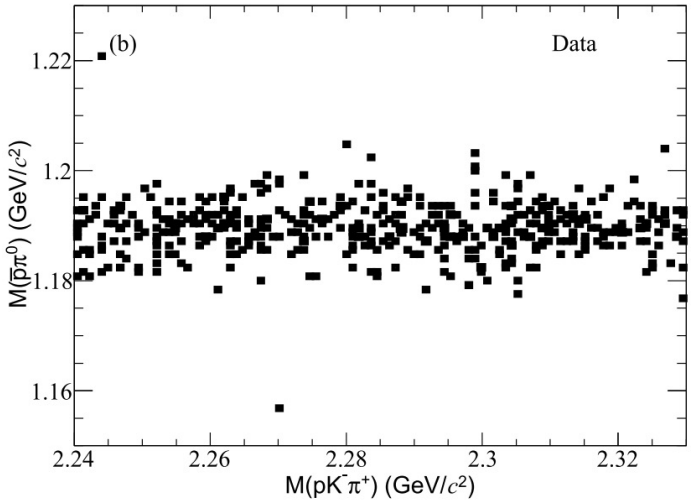


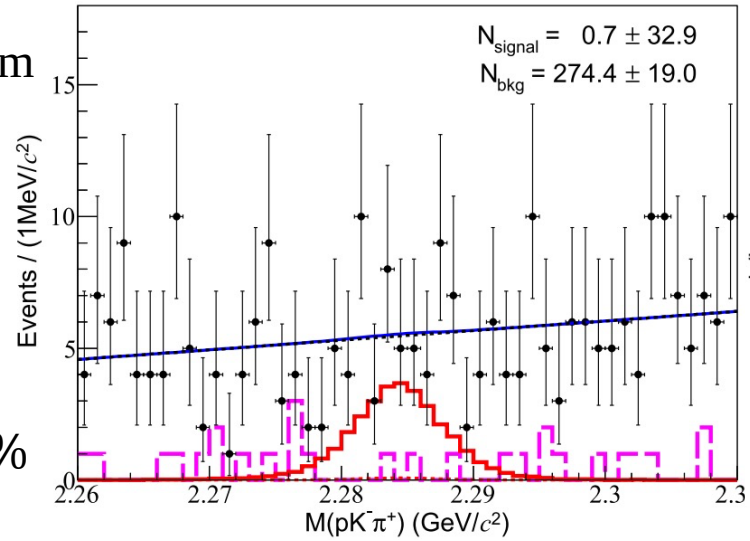
Search for the rare decay $\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^-$

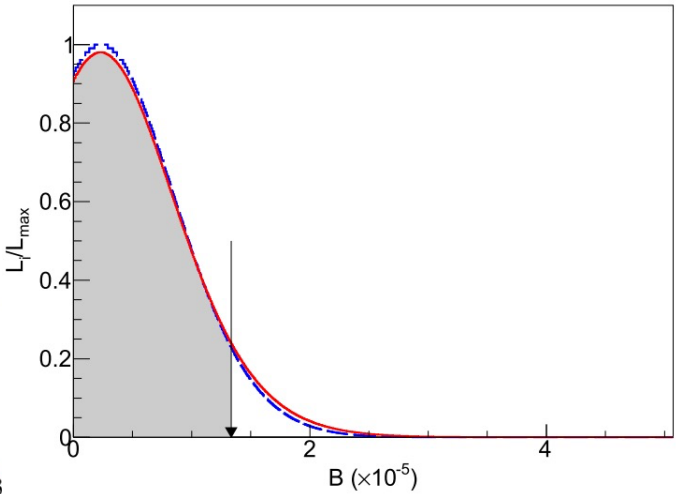
- Study the low energy QCD effects that determine the hadronic transition matrix elements and to find evidence of new physics in the process
- Using $(448.1 \pm 2.9) \times 10^6$ $\psi(3686)$ events
- $\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^-, \Lambda_c^+ \to pK^-\pi^+, \bar{\Sigma}^- \to \bar{p}\pi^0$
- Signal yield is extracted from an unbinned maximum likelihood fit to the $M(pK^-\pi^+)$ distribution
- Two main backgrounds: (1) $\psi(3686) \to K^*(892)^- p\bar{\Lambda}$ (2) $\psi(3686) \to \bar{K}^{*0}(892)p\bar{\Sigma}^-$
- $\mathcal{B}(\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^- + c.c.) < 1.4 \times 10^{-5}$ @ 90% C.L.

Chin Phy C, 47, 013002 (2023)



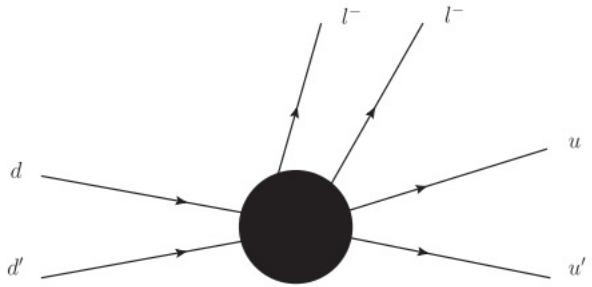


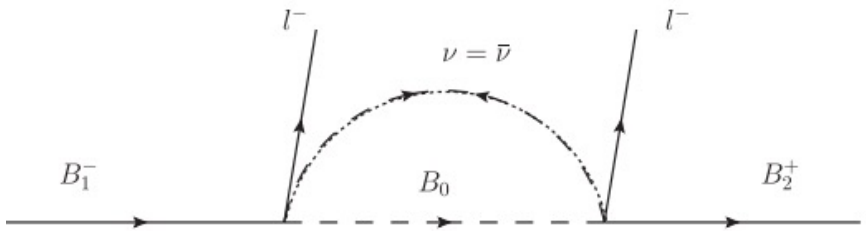




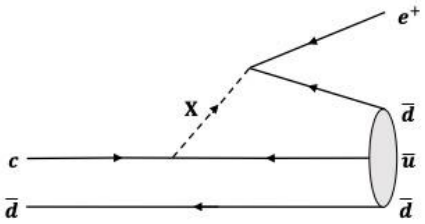
Search for LNV/BNV decays at BESIII

- **Search for LNV decay $\Sigma^- \to p e^- e^-$ and rare inclusive decay $\Sigma^- \to \Sigma^+ X$**

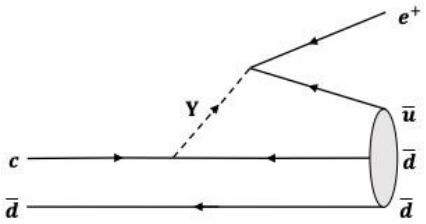




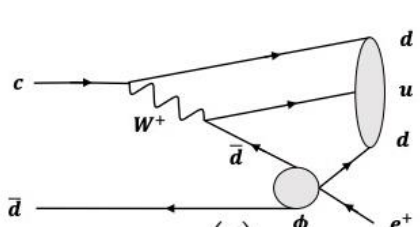
- **Search for baryon and lepton number violation decay $D \to ne/\ D^0 \to pe$**



(a)



(b)



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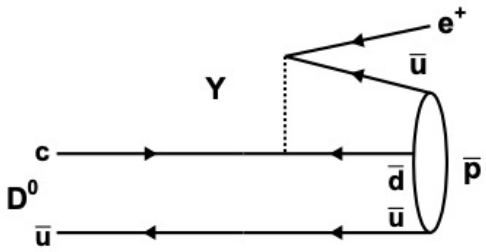

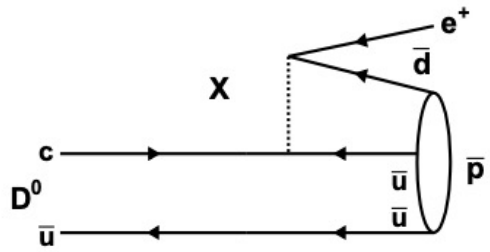

Search for LNV decay $\Sigma^- \to pe^-e^-$ and rare inclusive decay $\Sigma^- \to \Sigma^+X$

- The limits of lepton number violating (LNV) decays could be translated into more stringent conditions on the parameters of the new theoretical developments.
- Using $(1310.6 \pm 7.0) \times 10^6$ J/ψ events
- Σ^- is obtained through $J/\psi \to \bar{\Sigma}(1385)^+\Sigma^-$
- $M_{recoil} = \sqrt{(E_{J/\psi} - E_{\bar{\Lambda}} - E_{\pi^+})^2 - (\vec{p}_{J/\psi} - \vec{p}_{\bar{\Lambda}} - \vec{p}_{\pi^+})}$
- To determine the DT yield, we search for candidates in the M_{recoil} distributions for $\Sigma^- \to pe^-e^-$ and $\Sigma^- \to \Sigma^+X$ in data
- $\mathcal{B}(\Sigma^- \to pe^-e^-) < 6.7 \times 10^{-5}$ @ 90% C.L.

  $\mathcal{B}(\Sigma^- \to \Sigma^+X) < 1.2 \times 10^{-4}$ @ 90% C.L.

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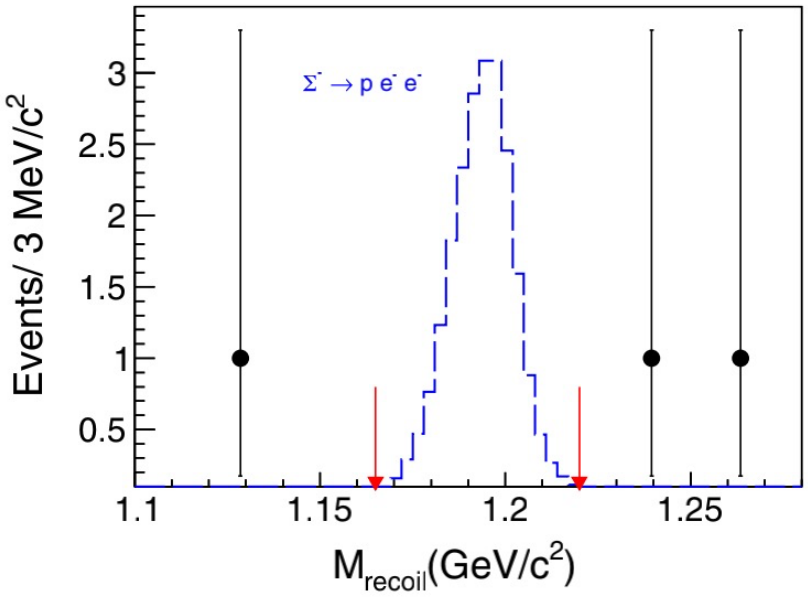
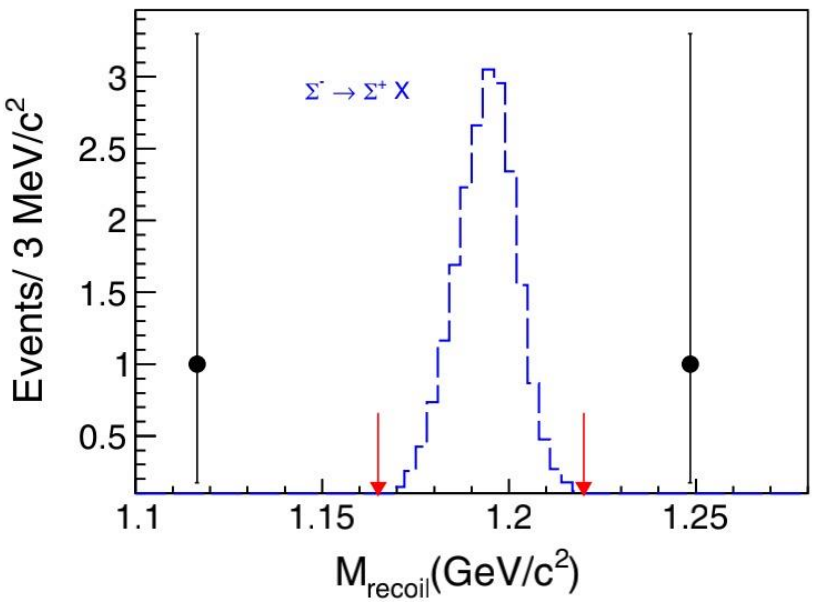
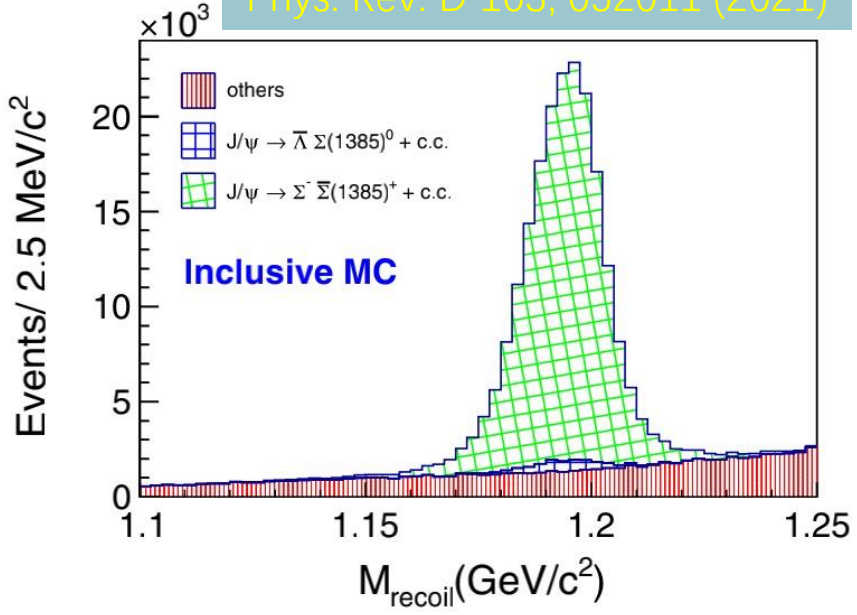






Search for baryon and lepton number violation decay $D \to ne$/ $D^0 \to pe$

2.93fb^{-1} data

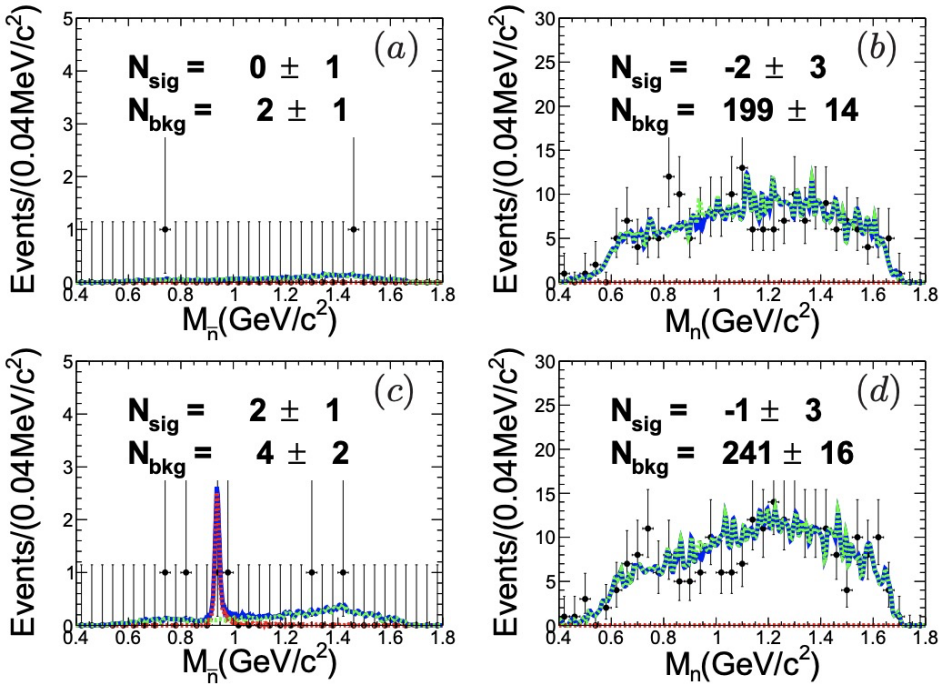
◆Excess of baryons over antibaryons in the Universe → BNV processes exist, BNV is allowed in GUTs and some SM extensions

◆With flavor of D determined from tag side

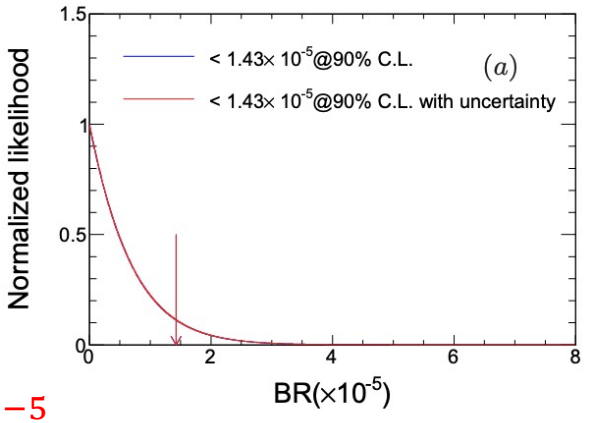
$\mathcal{B}(D^0 \to e^+\bar{p}) < 1.2 \times 10^{-6}$ @ 90% C.L.

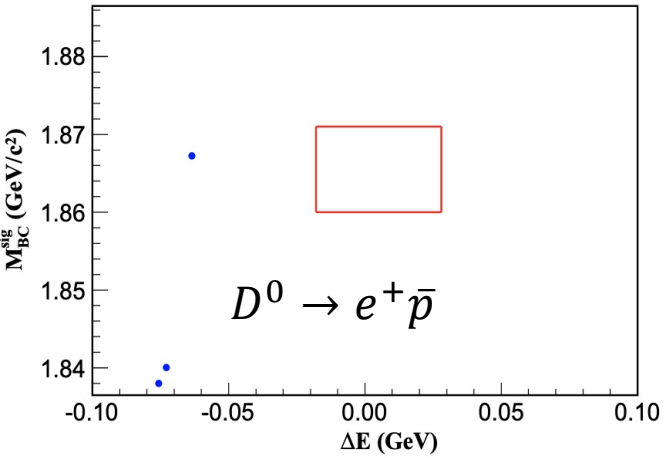
$\mathcal{B}(D^0 \to pe^-) < 2.2 \times 10^{-6}$ @ 90% C.L.

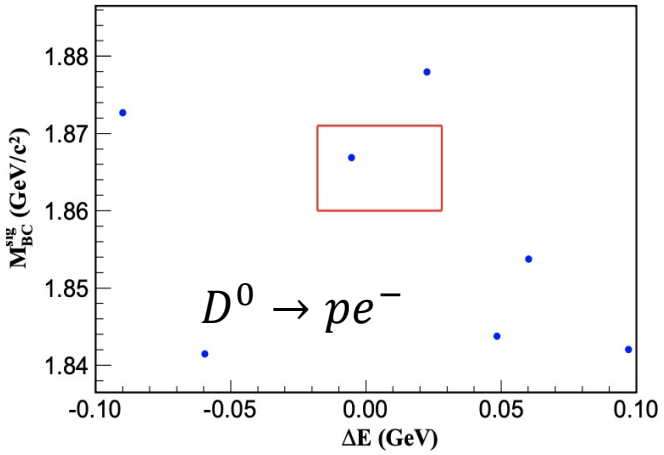
Phys. Rev. D 105, 032006 (2022)
Phys. Rev. D 106, 112009 (2022)



◆ $\bar{n}, n$ are regarded as missing particle with momentum & mass inferred from beam condition

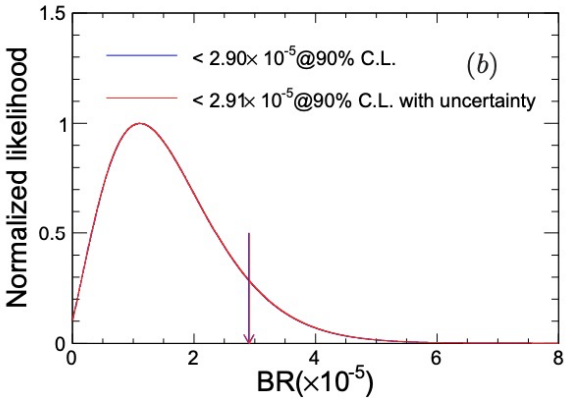






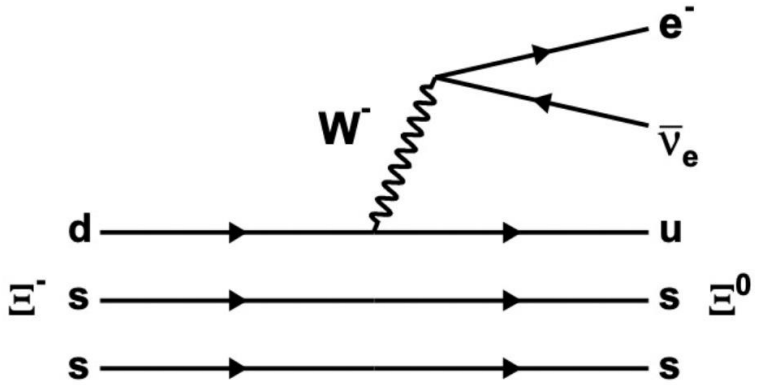
◆$\mathcal{B}(D^+ \to \bar{n}e^+) < 1.43 \times 10^{-5}$ @ 90% C.L. , $\Delta|\mathrm{B} - L| = 0$

$\mathcal{B}(D^+ \to ne^+) < 2.92 \times 10^{-5}$ @ 90% C.L. , $\Delta|\mathrm{B} - L| = 2$

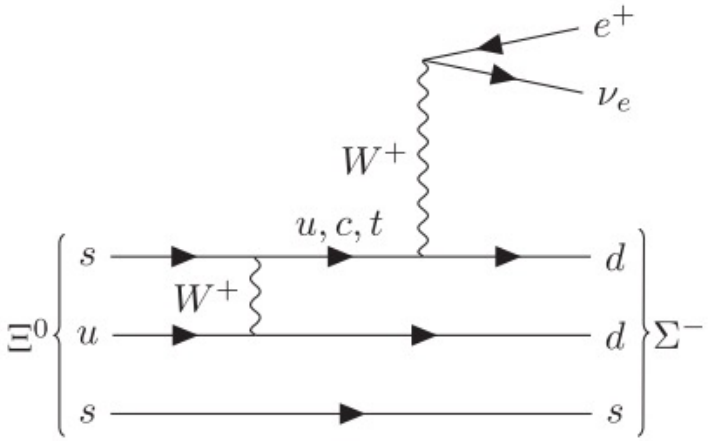


Search for hyperon semileptonic decays at BESIII

- **Search for the hyperon semileptonic decay $\Xi^- \to \Xi^0 e^- \bar{\nu}$**



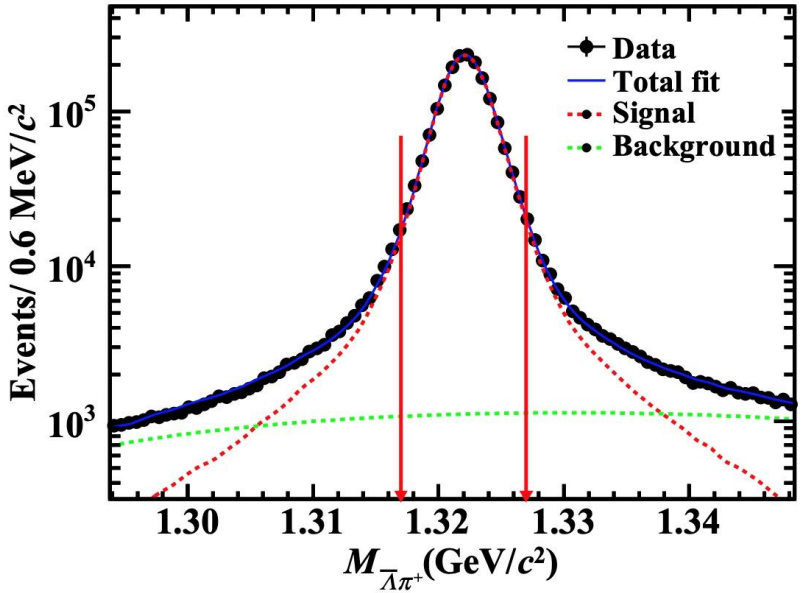
- **Search for the hyperon $\Delta S = \Delta Q$ process $\Xi^0 \to \Sigma^- e^+ \nu$**

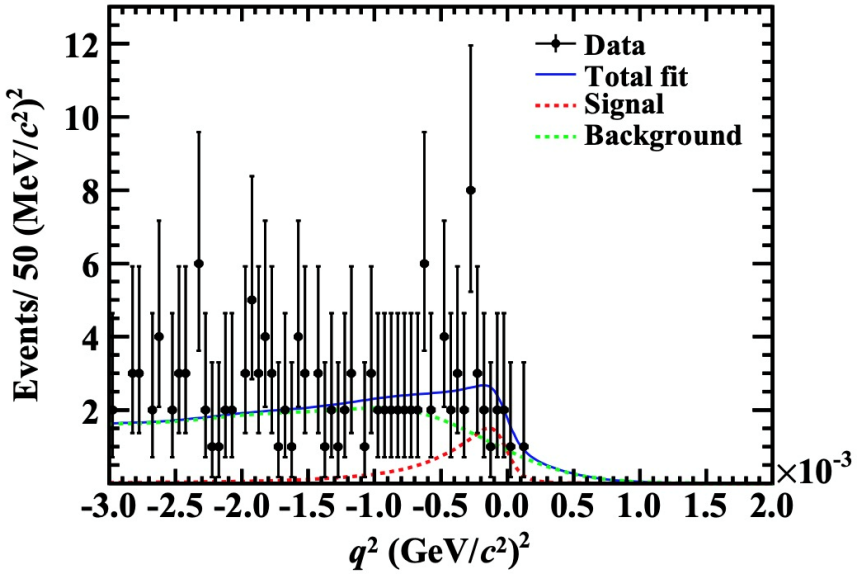


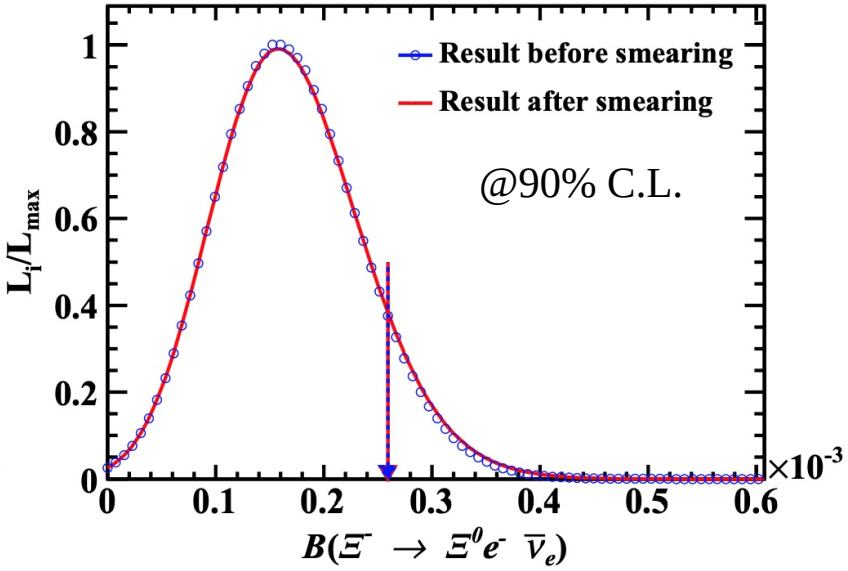
Search for hyperon semileptonic decay $\Xi^- \to \Xi^0 e^- \bar{\nu}$

- Hyperon semi-leptonic decays provide important information on the interplay between weak interactions and hadronic structures formed through strong interactions
- Using $(10.087 \pm 0.044) \times 10^9$ J/ψ events
- $M^{\text{recoil}}_{\bar{\Lambda}\pi^+} = \sqrt{(E_{\text{CM}} - E_{\bar{\Lambda}\pi^+})^2 - |\vec{p}_{\bar{\Lambda}\pi^+}|^2}$
- To extract the DT yield, the invariant mass squared of the lepton-neutrino system, $q^2 = (E_{\text{CM}} - E_{\bar{\Xi}^+} - E_{\Xi^0})^2 - (\vec{p}_{\text{CM}} - \vec{p}_{\bar{\Xi}^+} - \vec{p}_{\Xi^0})^2$
- $\mathcal{B}(\Xi^- \to \Xi^0 e^- \bar{\nu}_e) < 2.59 \times 10^{-4}$ @ 90% C.L.

Phys. Rev. D 104, 072007 (2021)







Search for the hyperon $\Delta S = \Delta Q$ process $\Xi^0 \to \Sigma^- e^+ \nu$

Phys. Rev. D 107, 012002 (2023)

◆$\Delta S = \Delta Q$: change in strangeness should have the same sign as charge

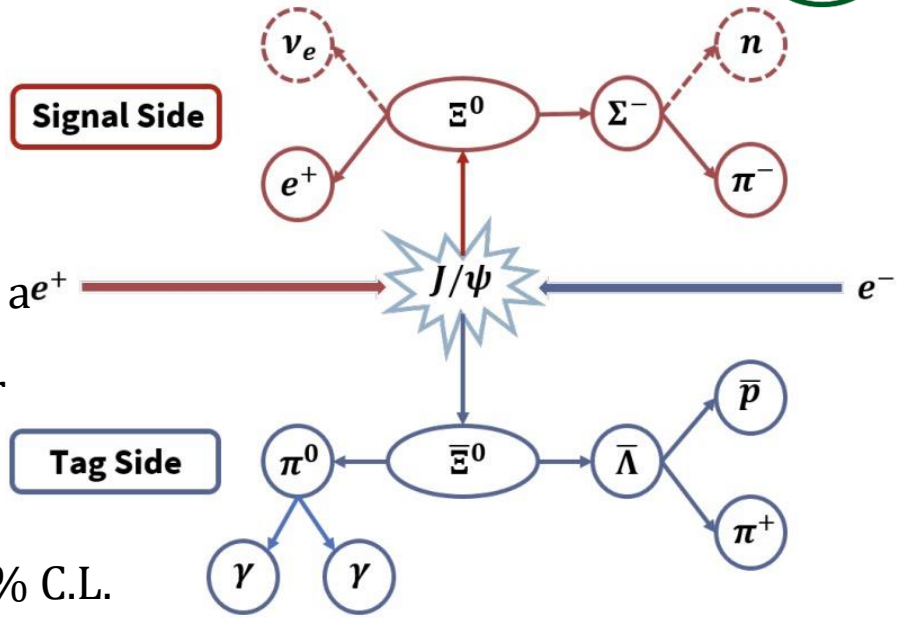
◆First attempt to measure the absolute BF of this decay process in a collider experiment

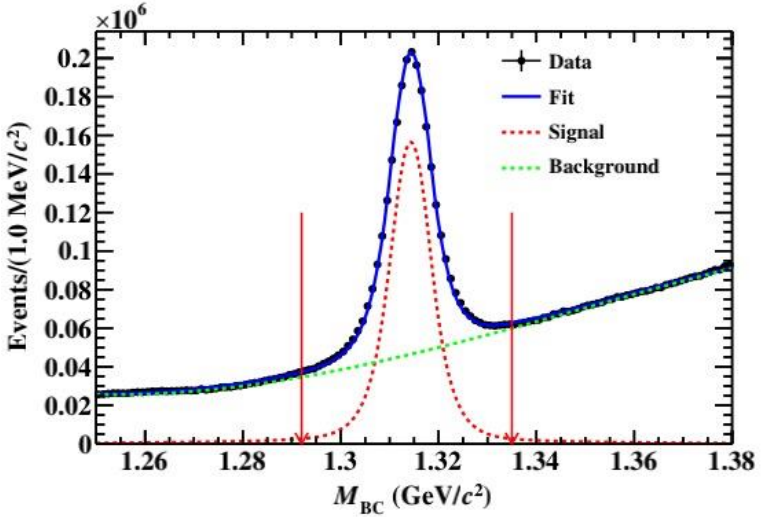
◆Using $(1.0087 \pm 0.0044) \times 10^{10}$ J/ψ events

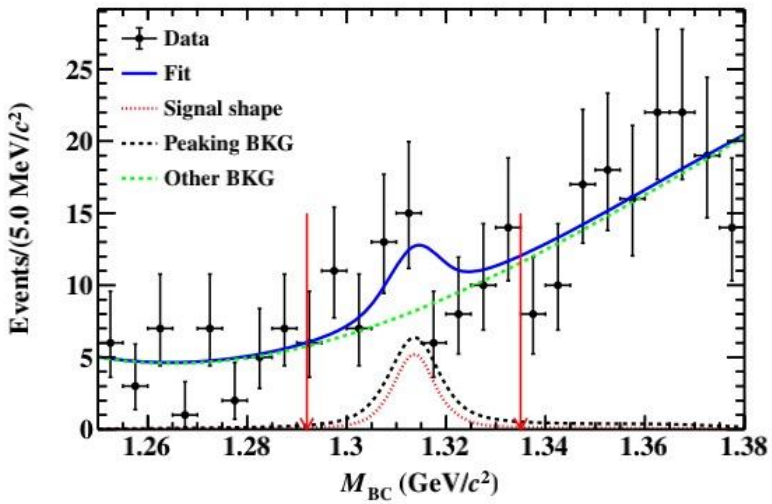
◆Use dE/dx χ value, P_{π^-}, P_{e^-} for the DT further event selection

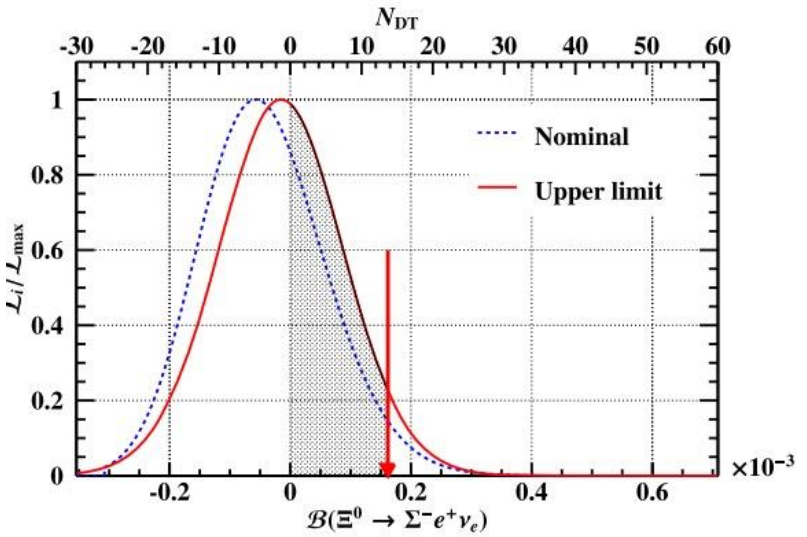
◆DT yield is measured by performing a fit to the M_{BC} distribution of ST side for DT candidates.

◆$\mathcal{B}(\Xi^0 \to \Sigma^- e^+ \nu) < 1.6 \times 10^{-4}$ @ 90% C.L.



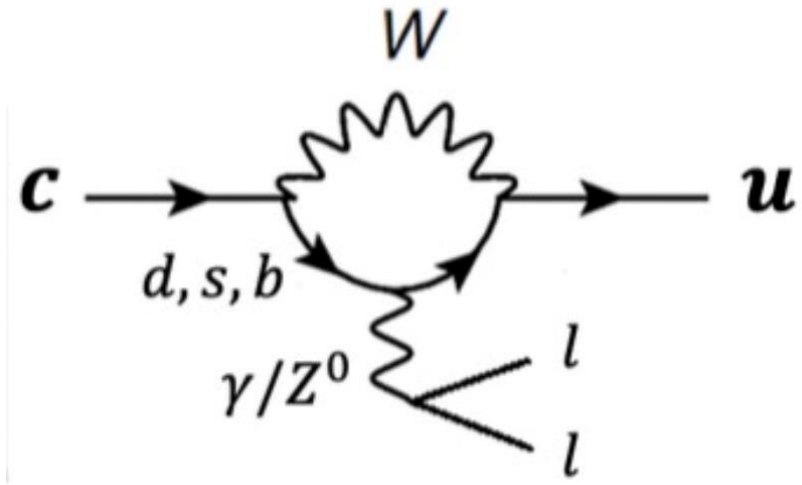






Search for FCNC rare decays at BESIII

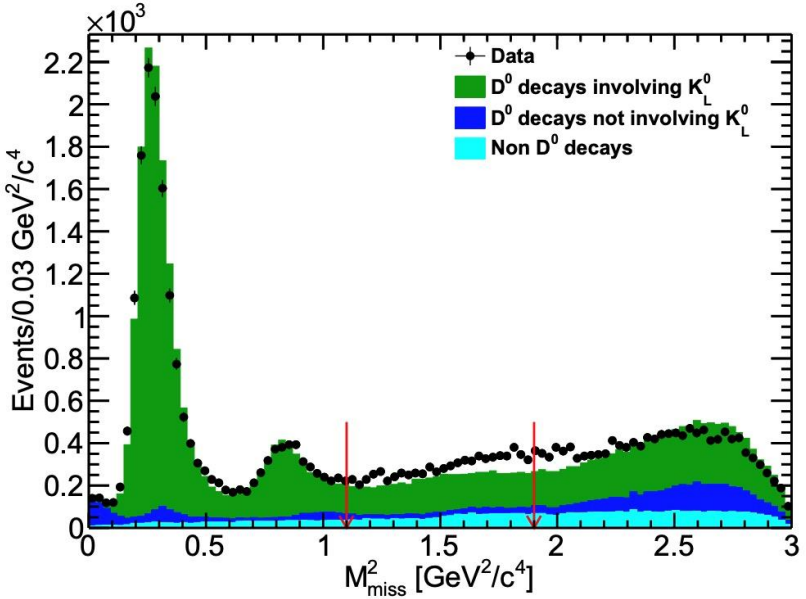
- **Search for the FCNC process $D^0 \to \pi^0 \nu \bar{\nu}$**

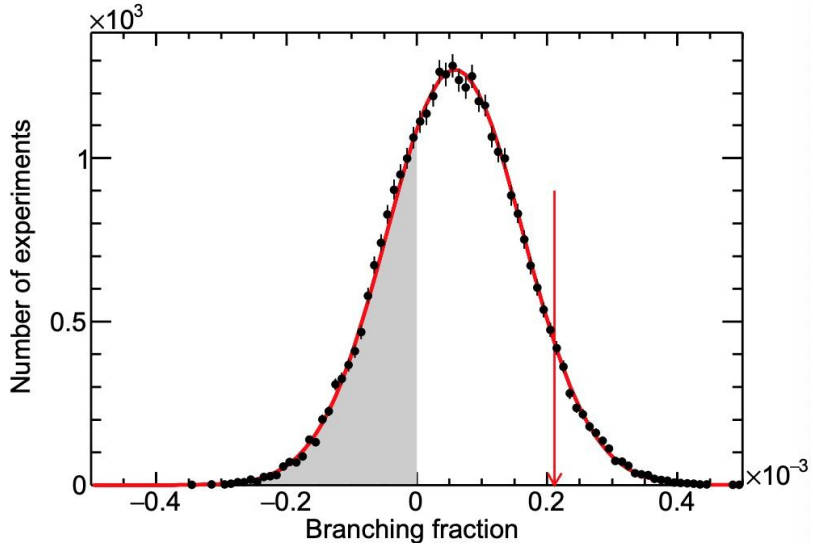


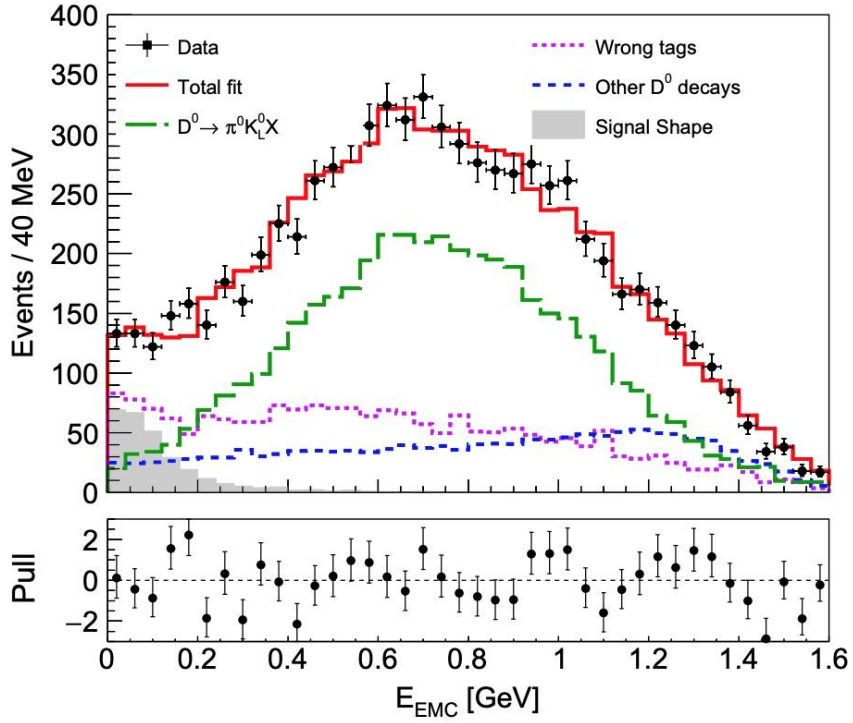
Search for the FCNC process $D^0 \to \pi^0 \nu\bar{\nu}$

- In SM, FCNC is strongly suppressed by GIM mechanism and can happen only through 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 system due to stronger diagram cancellation than the down-type quarks
- Discriminator: EMC energy not associated with signal and tag decays
- $M^2_{\text{miss}} = (E_D)^2/c^4 - |\vec{p}_{\pi^0}|^2/c^4$
- $\mathcal{B}(D^0 \to \pi^0\nu\bar{\nu}) < 2.1 \times 10^{-4}$ @ 90% C.L.
- Provide a clean probe to search for New Physics in charm sector
- The first experimental results of search for c $\to u\nu\bar{\nu}$ processes

Phys. Rev. D 105, L071102 (2022)







Search for charged lepton flavor violating decay

- **Search for CLFV decay $J/\psi \to e\tau$**
- **Search for CLFV decay $J/\psi \to e\mu$**

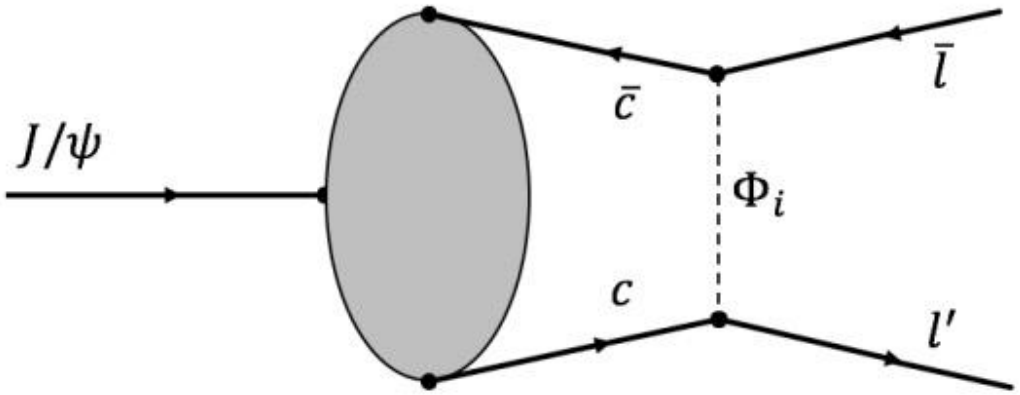


Diagram via leptoquarks

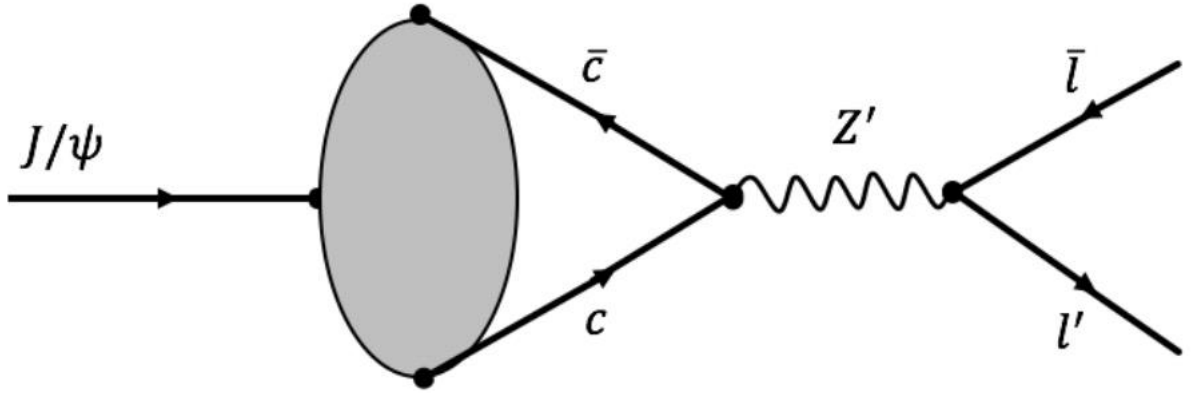


Diagram via a Z' in TC2 models

Phys. Lett. B 496, 89 (2000)

Search for charged lepton flavor violating decay

◆New physics models predicting $\mathcal{B}(J/\psi \to e\mu)$ to $10^{-16}\sim10^{-9}$, $\mathcal{B}(J/\psi \to e\tau)$ to $10^{-10}\sim10^{-8}$

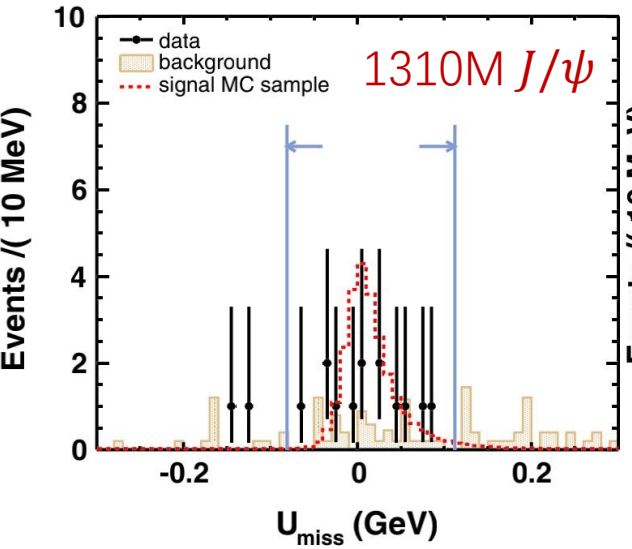
$J/\psi \to e\tau$

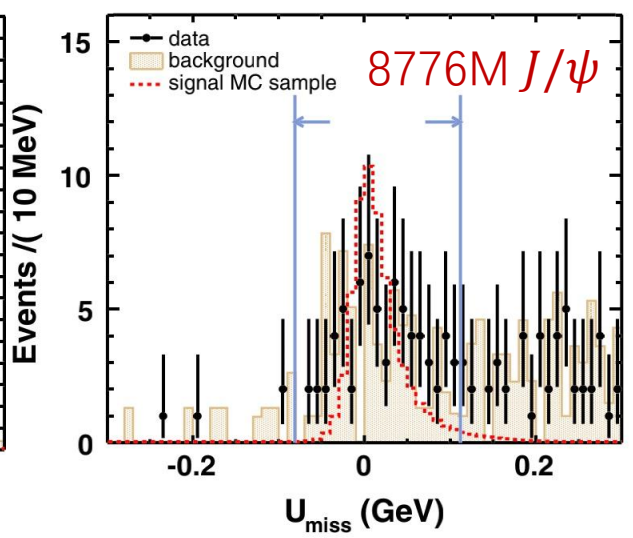
◆$J/\psi \to e\tau, \tau \to \pi\pi^0\nu, U_{miss} = E_{miss} - c|\vec{P}_{miss}|$

◆$\mathcal{B}(J/\psi \to e\tau)$<7.5× 10^{-8} @ 90% C.L.

◆The 1st submitted paper based on full 10 billion J/ψ data of BESIII

Phys. Rev. D 103, 112007 (2021)





$J/\psi \to e\mu$

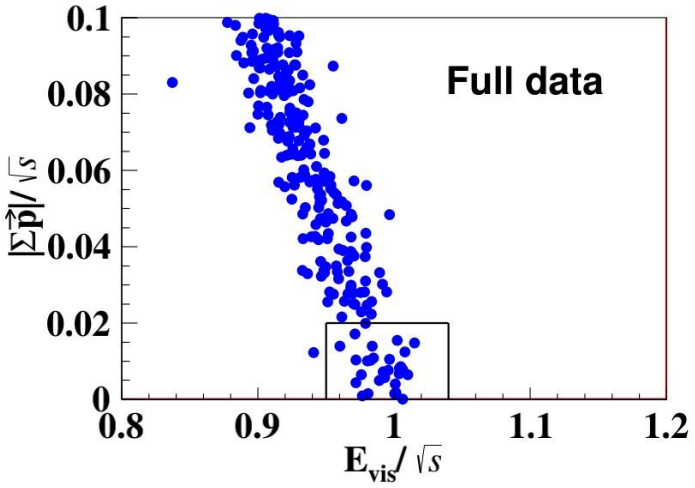
◆Using 8.998 × 10^9 J/ψ events

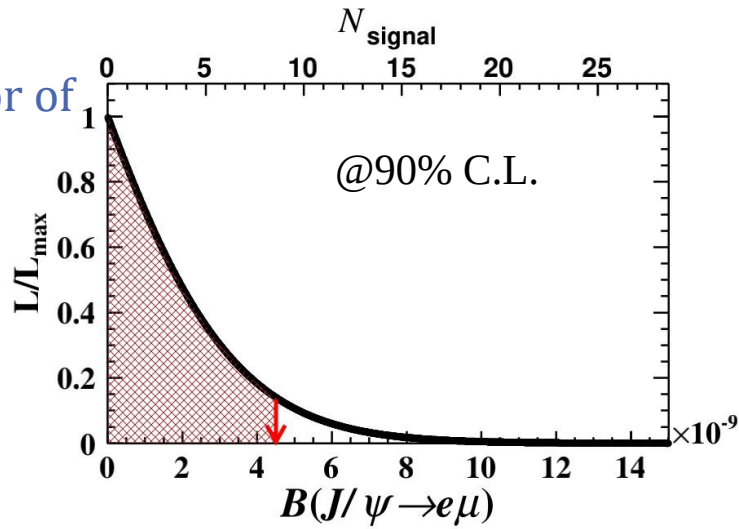
◆$\mathcal{B}(J/\psi \to e\mu)$<4.5× 10^{-9} @ 90% C.L.

◆Improves the previous published limits by a factor of more than 30

◆The most precise result of CLFV search in heavy quarkonium systems

Sci. Chin. Phys. Mech. Astron. 66 2 (2023)





Summary

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

Thank you