BESIII

Search for BSM rare charm decays at BESIII

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On behalf of BESIII Collaboration

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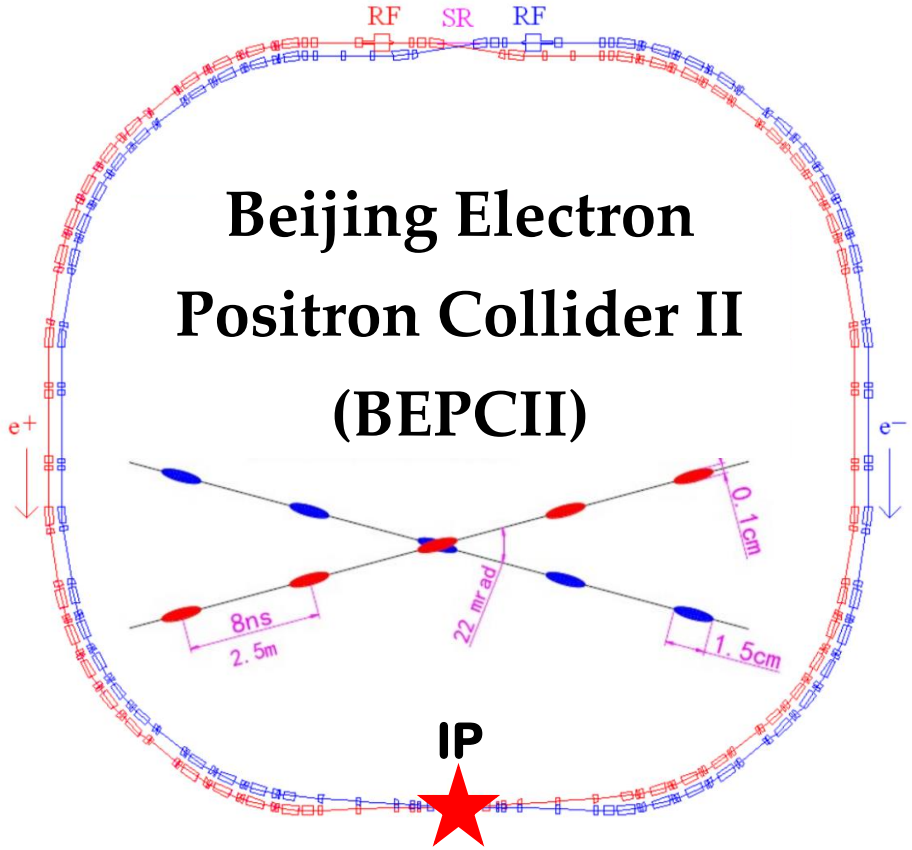
Outline

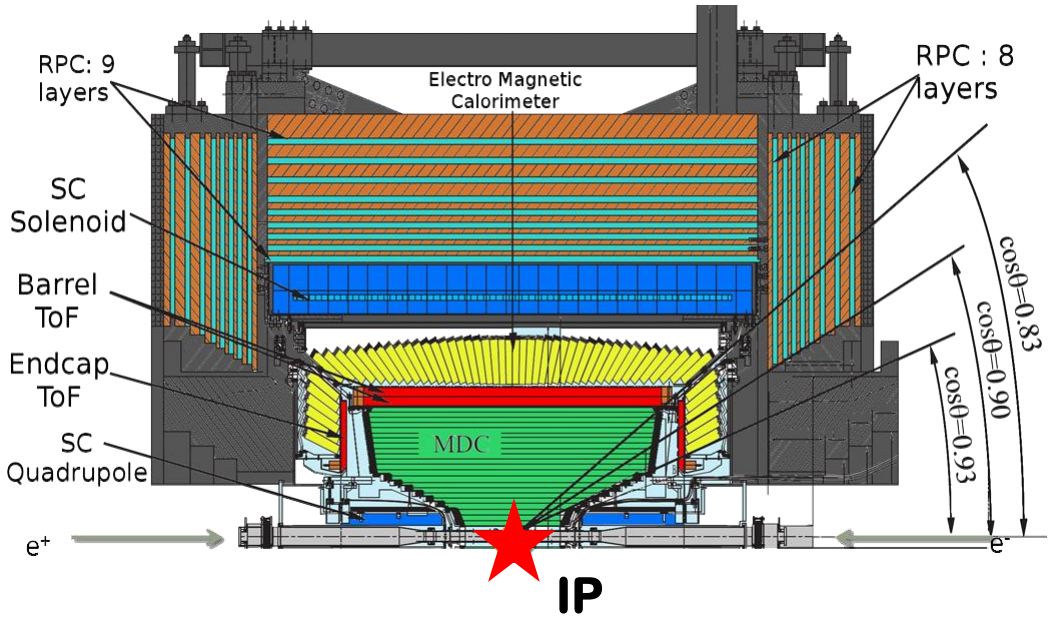
- BEPCII and BESIII
- BESIII data samples
- Search for charmonium weak decays
- Search for CLFV decays
- Search for BNV/LNV decays
- Search for FCNC decays
- Summary

BEPCII and BESIII



- **Operation energy :** 1.0 ~ 2.45 GeV
- **Optimized energy :** 1.89 GeV
- **Luminosity :** $1 \times 10^{33}\ cm^{-2}s^{-1}$

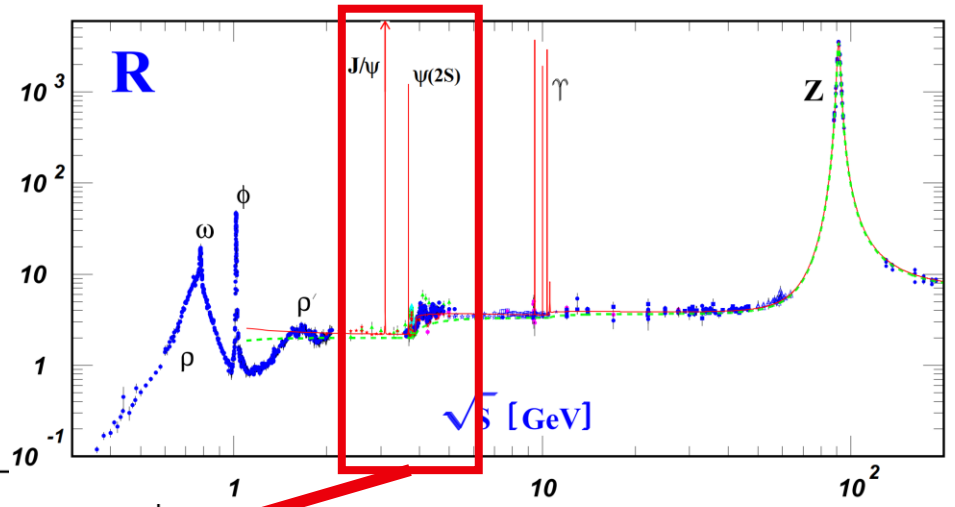
Beijing Spectrometer(BESIII) Experiment

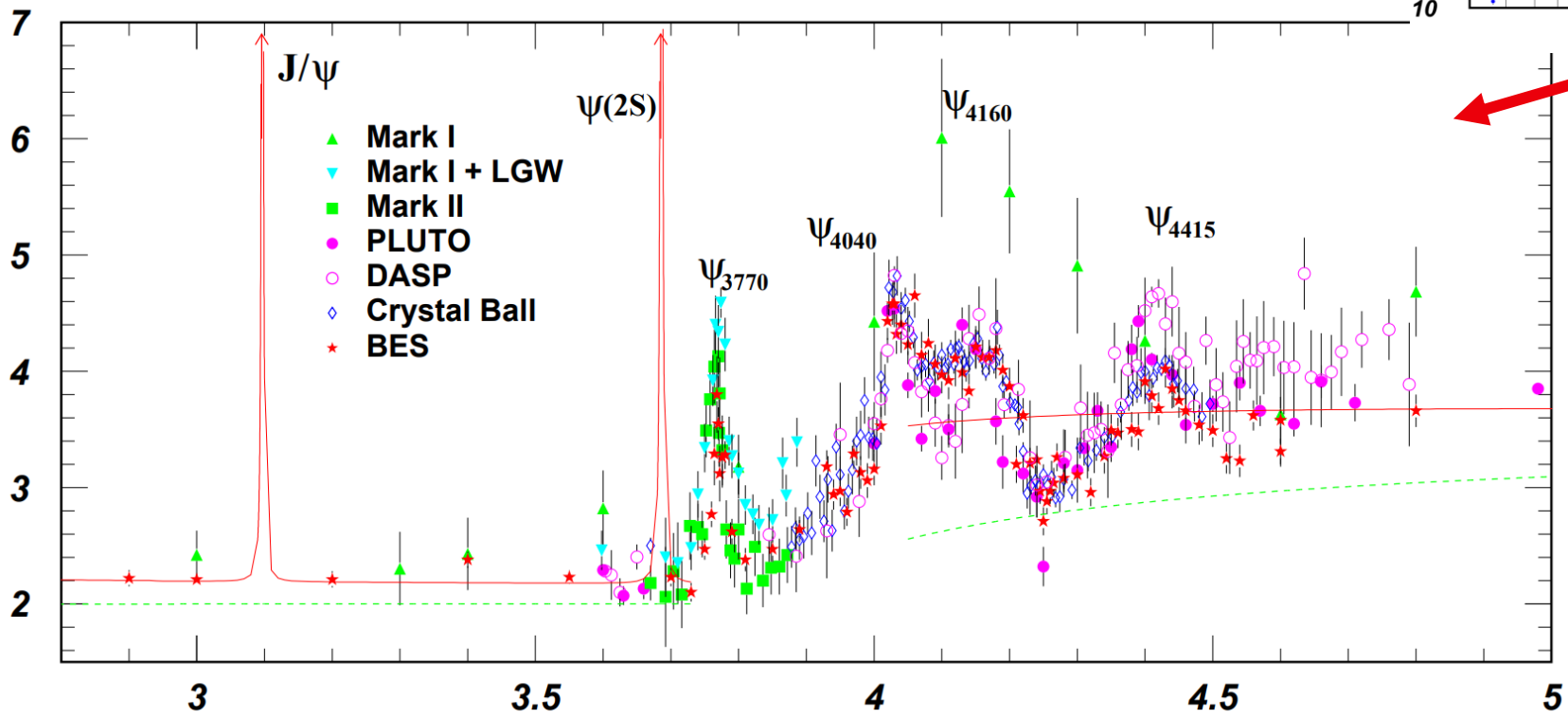


- **MDC** $\begin{cases} \sigma_p = 0.5\%\ @\ 1\ \mathrm{GeV/c} \\ dE/dx : 6\% \end{cases}$
- **TOF** $\sigma_t = 68(60)\ ps$ barrel(endcap)
- **EMC** $\sigma_E = 2.5\%(5\%)\ @\ 1\ \mathrm{GeV/c}$ barrel(endcap)

BESIII data samples

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





- J/ψ 1.0×10^{10}
- $\psi(3686)$ 2.6×10^{9}
- $\psi(3770)$ $2.9\ fb^{-1}$
- $\psi(4040)$ $0.5\ fb^{-1}$
- $\psi(4160)$ $3.2\ fb^{-1}$
- $\psi(4415)$ $1.1\ fb^{-1}$

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"

Search for charmonium weak decays

- **Search for the charmonium weak decay $J/\psi \to D^- e^+ \nu_e + c.c.$**
- **Search for the charmonium weak decay $J/\psi \to D^- \mu^+ \nu_\mu + c.c.$**
- **Search for the charmonium weak decay $\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^- + c.c.$**

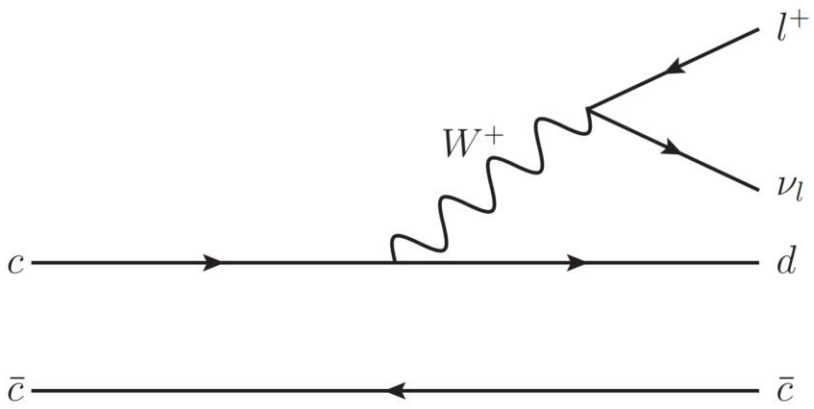
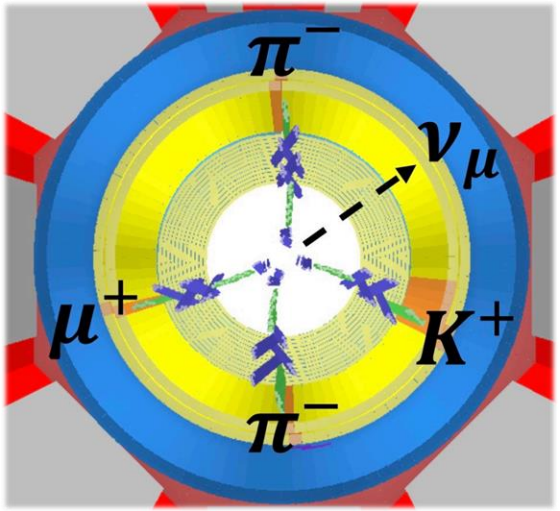


Diagram of $J/\psi \to D^- l^+ \nu_l$



Event display of $J/\psi \to D^- \mu^+ \nu_\mu$

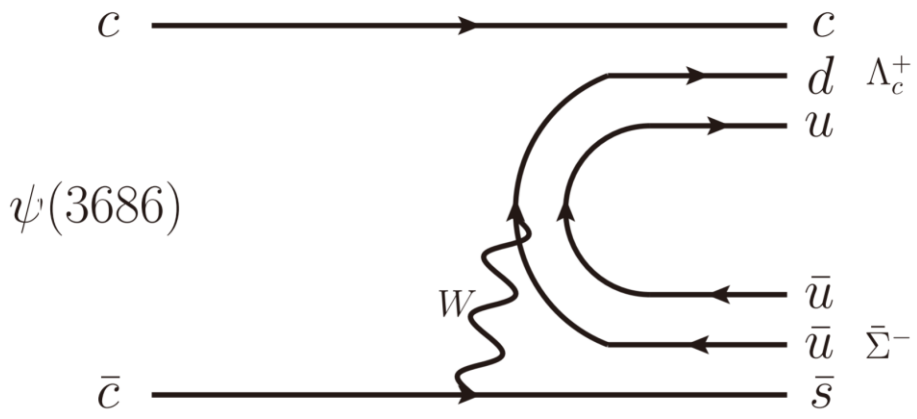


Diagram of $\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^-$

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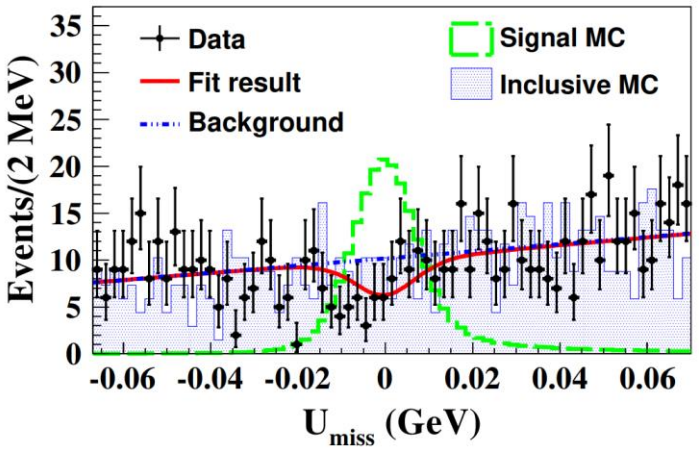
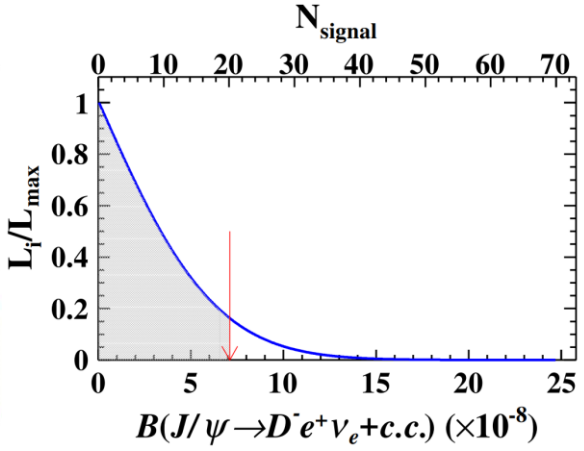
Search for $J/\psi \to D^- e^+ \nu_e$ / $J/\psi \to D^- \mu^+ \nu_\mu$

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

- $\mathcal{B}(J/\psi \to D^- e^+ \nu_e + c.c.) < 7.1 \times 10^{-8}$ @90% C.L.
- Puts a stringent constraint on the parameter spaces for different new physics models





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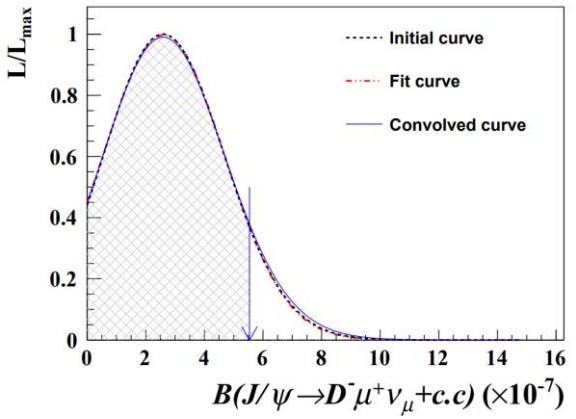
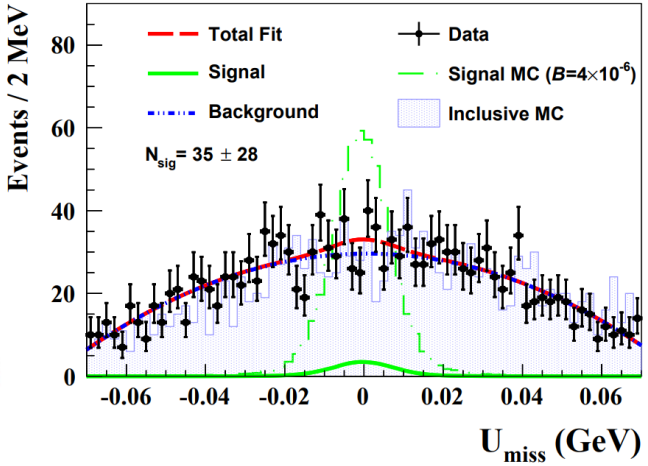
- $\mathcal{B}(J/\psi \to D^- \mu^+ \nu_\mu + c.c.) < 5.6 \times 10^{-7}$ @90% C.L.
- The first search of a charmonium weak decay with a muon in the final state.





arXiv:2307.02165

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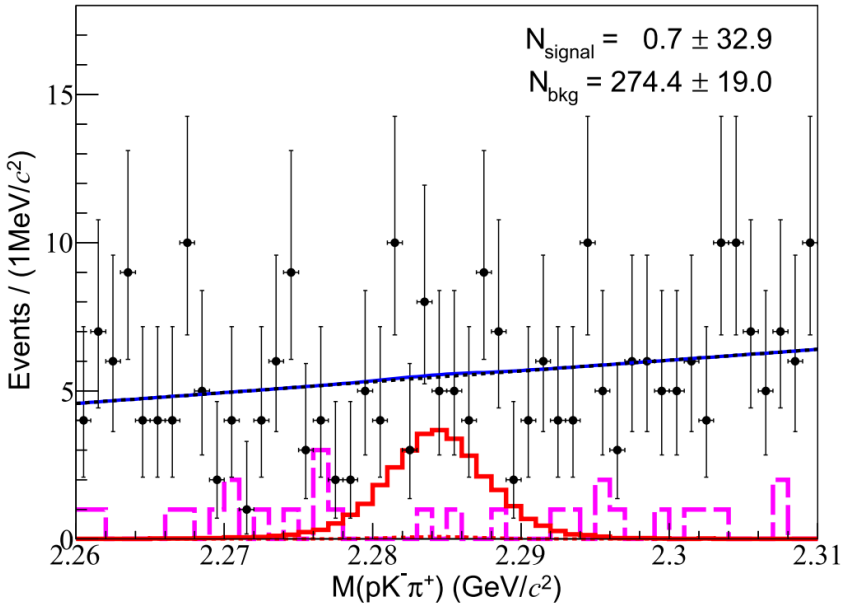
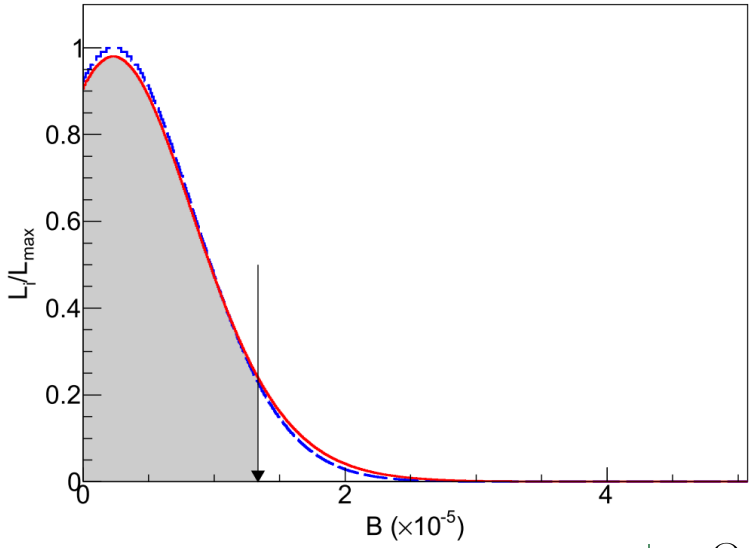
Search for $\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^- + c.c.$

- 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 from BESIII
- $\psi(3686) \to \Lambda_c^+ \bar{\Sigma}^-, \Lambda_c^+ \to pK^-\pi^+, \bar{\Sigma}^- \to \bar{p}\pi^0$
- Signal yield is extracted from an unbinned maximum likelihood fit to the $M(pK^-\pi^+)$ distribution
- Two main backgrounds:
  - $\psi(3686) \to K^*(892)^- p\bar{\Lambda}$
  - $\psi(3686) \to \bar{K}^{*0}(892) p\bar{\Sigma}^-$

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





Chin Phy C, 47, 013002 (2023)

Search for CLFV decays

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

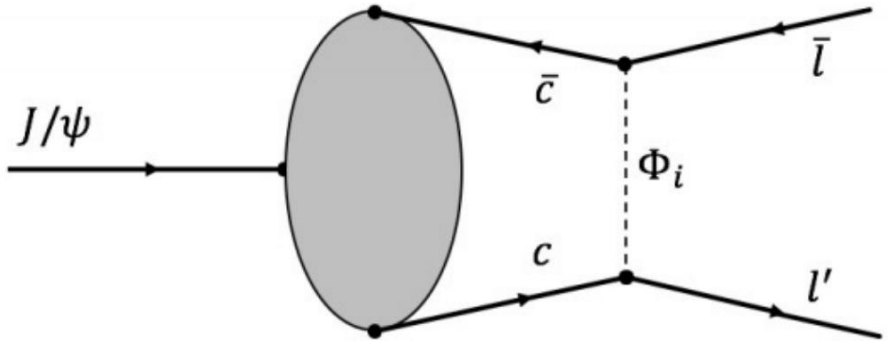


Diagram via leptoquarks

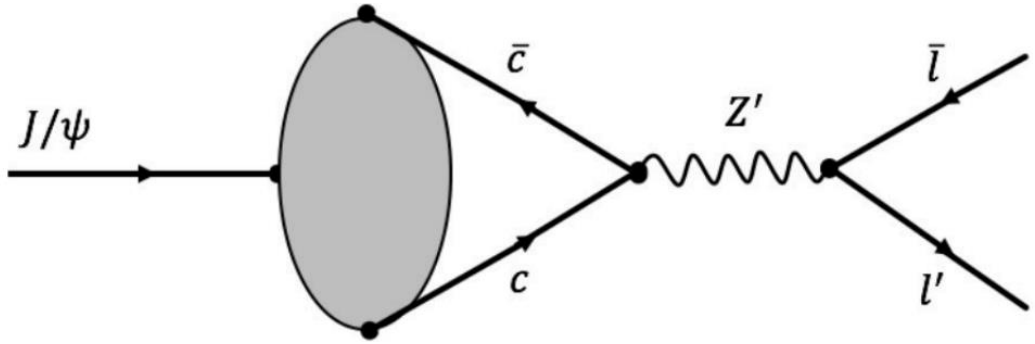


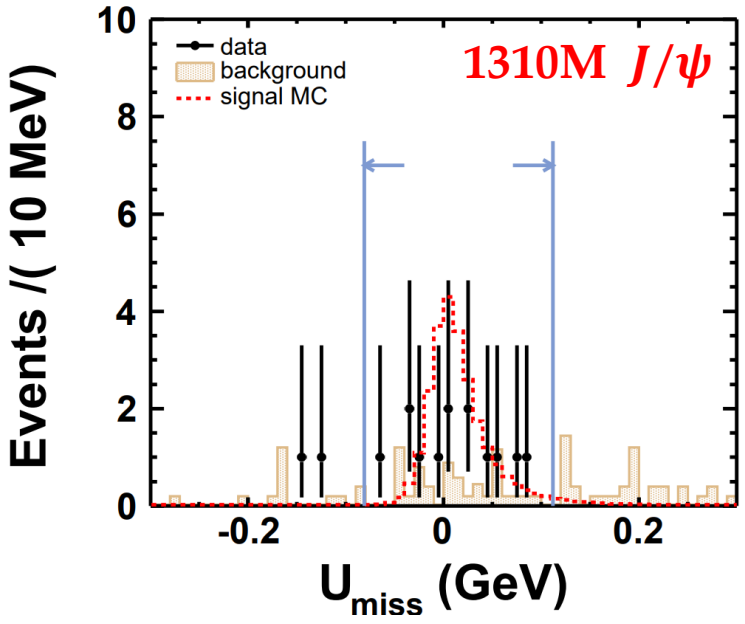
Diagram via a Z′ in TC2 models

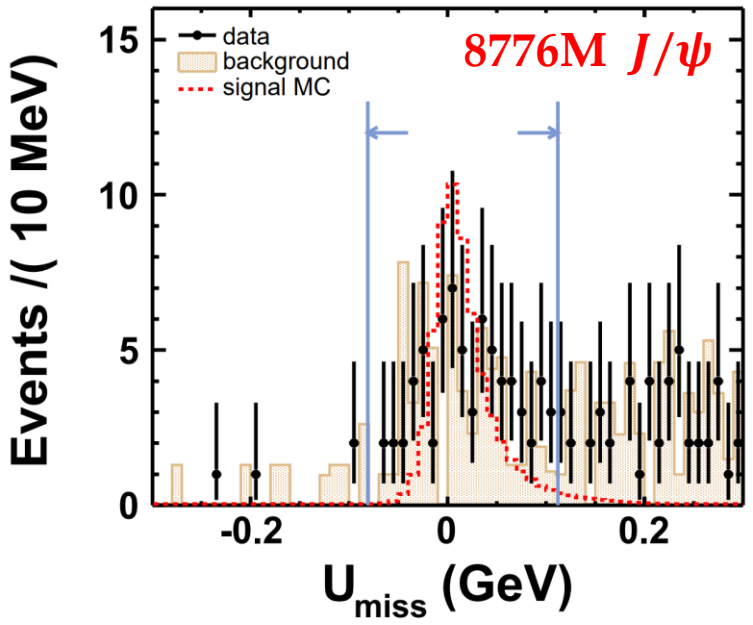
Phys. Lett. B 496, 89 (2000)

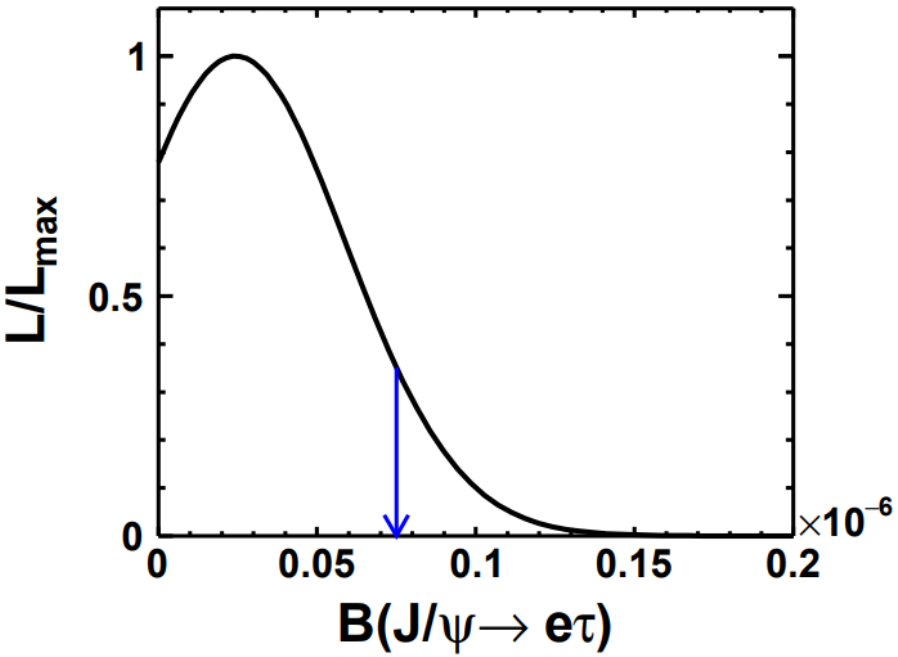
Charged lepton flavor violating (CLFV) decays

Search for the CLFV decay $J/\psi \to e\tau$

- In the SM, the CLFV process is forbidden
- New physics models predicting $\mathcal{B}(J/\psi \to e\tau) \sim 10^{-9}$
- The first submitted paper based on full 10 billion J/ψ data of BESIII
- $J/\psi \to e\tau, \tau \to \pi\pi^0\nu_\tau, U_{miss} = E_{miss} - c|\vec{P}_{miss}|$
- $\boldsymbol{\mathcal{B}(J/\psi \to e\tau) < 7.5 \times 10^{-8}}$ **@90% C.L.**







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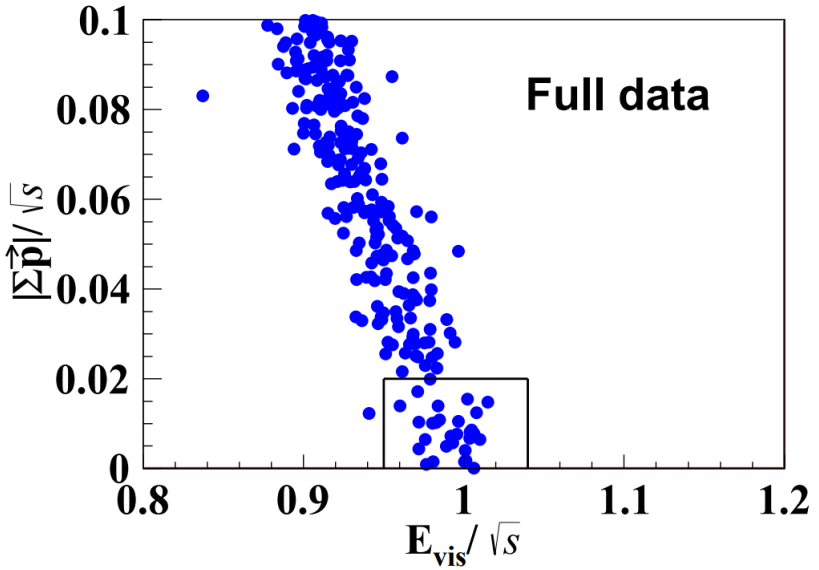
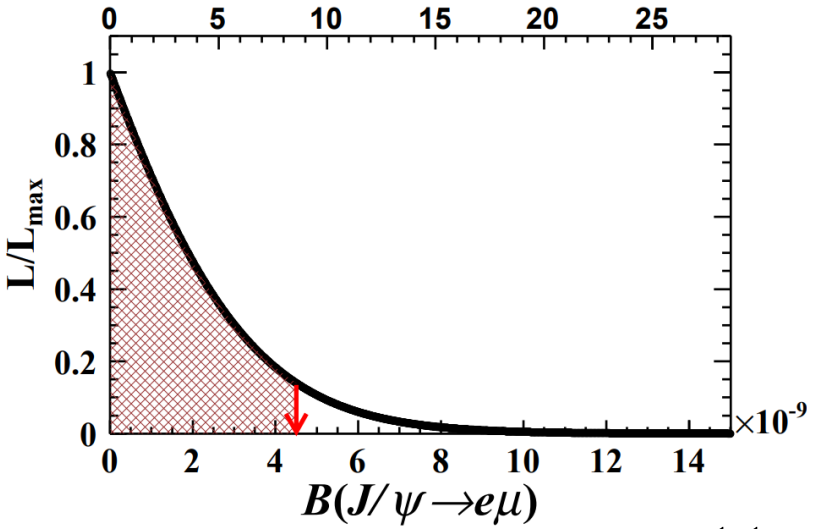
Search for the CLFV decay $J/\psi \to e\mu$

- New physics models predicting $\mathcal{B}(J/\psi \to e\mu)$ to be $10^{-8} \sim 10^{-16}$
- Using 8.998×10^9 J/ψ events
- Mainly two types of background:
  - J/ψ decays to two charged particles (using larger statistic MC samples to estimate)
  - e^+e^- annihilations into pairs of charged particles (using control sample to estimate)
- $\boldsymbol{\mathcal{B}(J/\psi \to e\mu) < 4.5 \times 10^{-9}}$ **@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

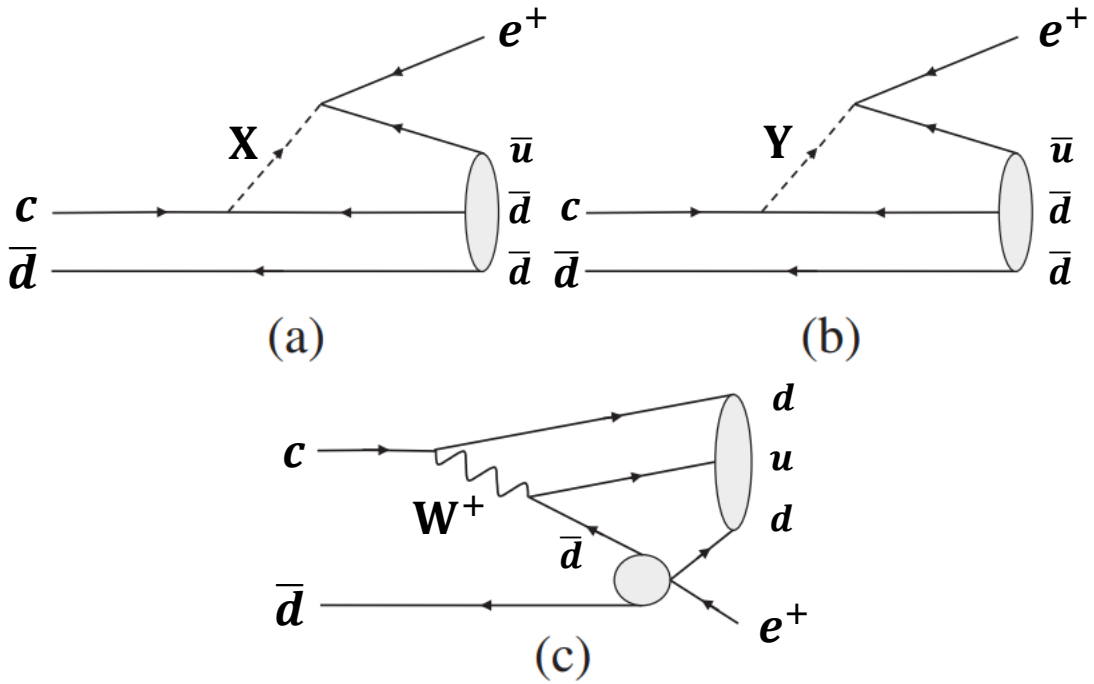




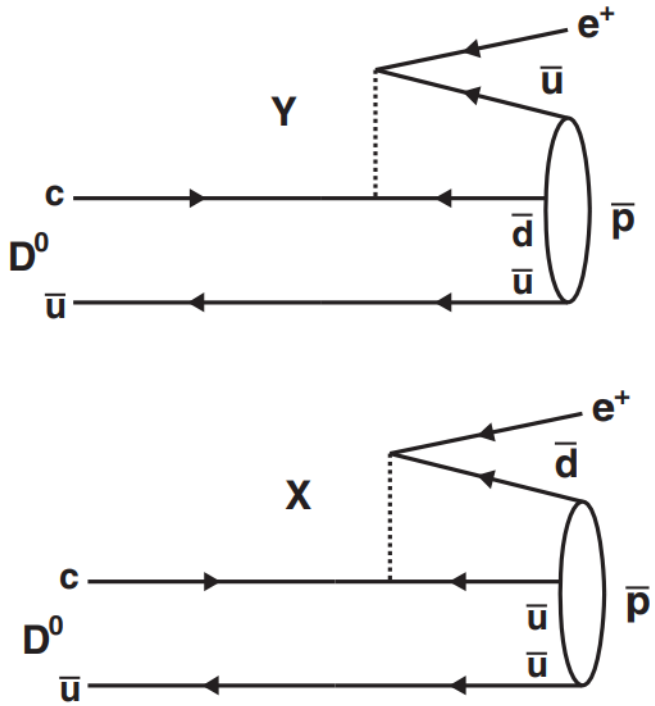
Sci. Chin. Phys. Mech. Astron. 66 2 (2023)

Search for BNV/LNV decays

- **Search for the baryon and lepton number violation decay $D^{\pm} \to n(\bar{n})e^{\pm}$**
- **Search for the baryon and lepton number violation decay $D^{0} \to \bar{p}(p)e^{\pm}$**



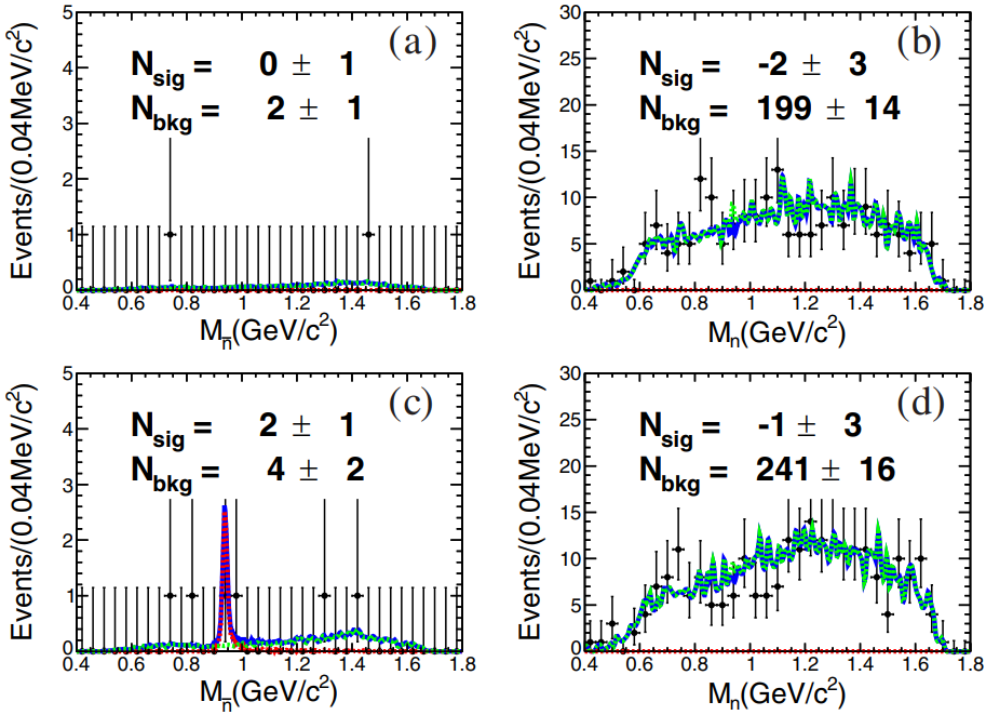
Feynman diagrams for $D^{+} \to \bar{n}e^{+}$ with heavy gauge bosons X (a) and Y (b), and $D^{+} \to ne^{+}$with elementary scalar fields ϕ (c)



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

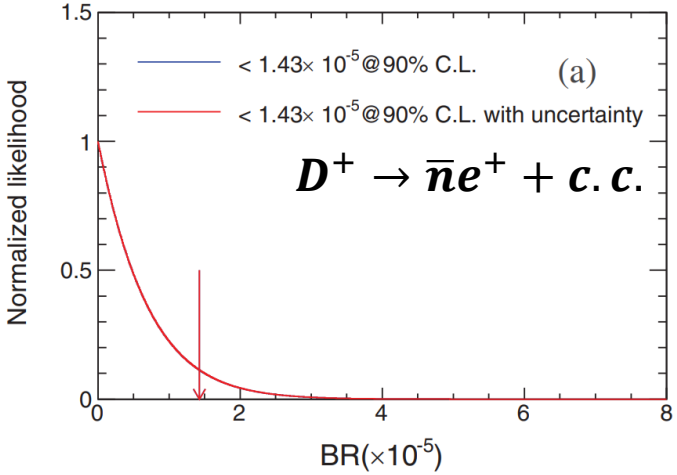
Search for $D^{\pm} \to n(\bar{n})e^{\pm}$

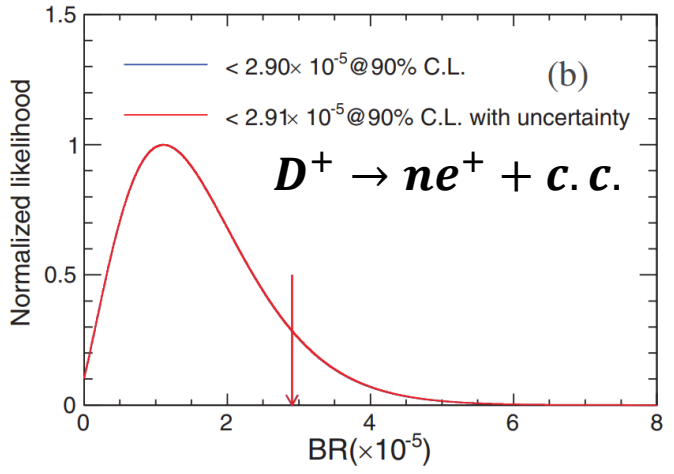
- Excess of baryons over antibaryons in the Universe → BNV processes exist, BNV is allowed in GUTs and some SM extensions.
- $\psi(3770) \to D^{+}D^{-}$, Double tag method: $D^{\pm} \to n(\bar{n})e^{\pm}$, and $D^{\mp}$ to 6 hadronic-decay modes.
- $n, \bar{n}$ are regarded as **missing particle** with momentum & mass inferred from beam condition.



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

- Using 2.93 fb^{-1} data at $\sqrt{s} = 3.773$ GeV from BESIII
- $\mathcal{B}(D^{+} \to \bar{n}e^{+} + c.c.) < 1.43 \times 10^{-5}$ @90% C.L.
- $\mathcal{B}(D^{+} \to ne^{-} + c.c.) < 2.92 \times 10^{-5}$ @90% C.L.





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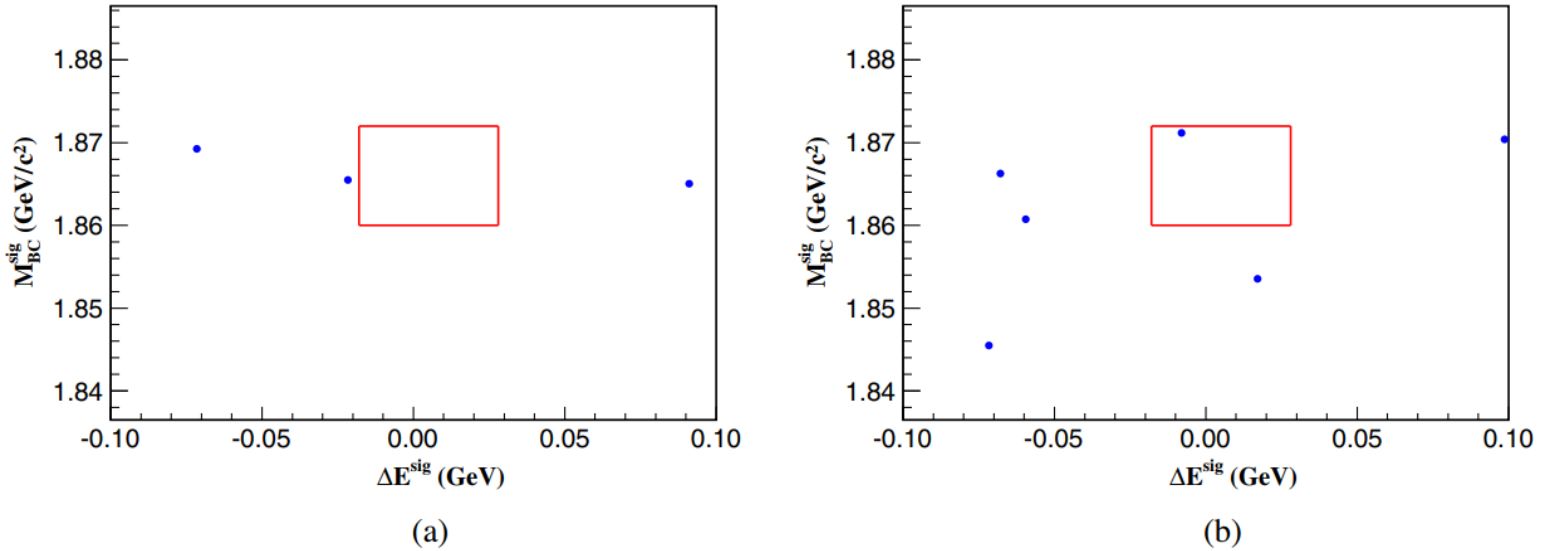
Search for $D^0 \to \bar{p}(p)e^{\pm}$

- Excess of baryons over antibaryons in the Universe → BNV processes exist, BNV is allowed in GUTs and some SM extensions.
- $\psi(3770) \to D^0\bar{D}^0$ (a very low background environment)
- Double tag method: $D^0 \to \bar{p}e^+$, and $\bar{D}^0$ is reconstructed via 3 hadronic decay modes.
- Using 2.93 fb^{-1} data at $\sqrt{s} = 3.773$ GeV from BESIII



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

- $\mathcal{B}(D^0 \to \bar{p}e^+ + c.c.) < 1.2 \times 10^{-6}$ @90% C.L.
- $\mathcal{B}(D^0 \to pe^- + c.c.) < 2.2 \times 10^{-6}$ @90% C.L.

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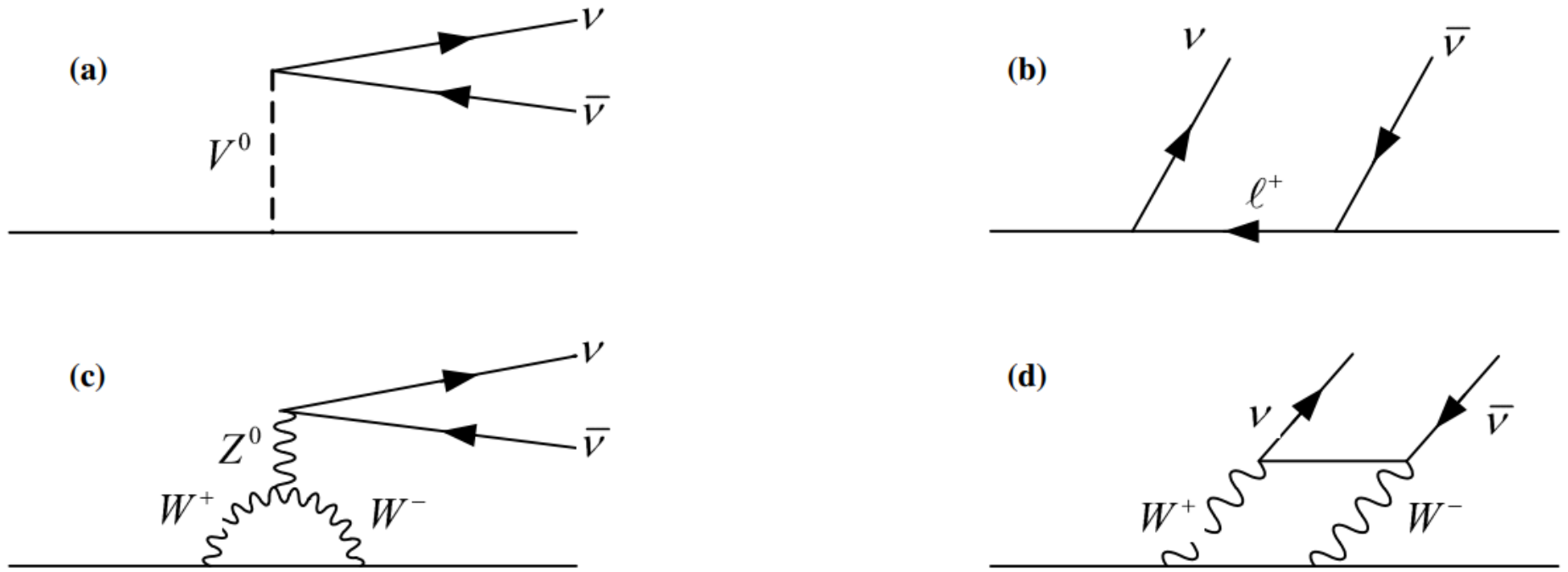
Search for FCNC decays

- **Search for the flavor changing neutral current decay $D^0 \to \pi^0 \nu \bar{\nu}$**

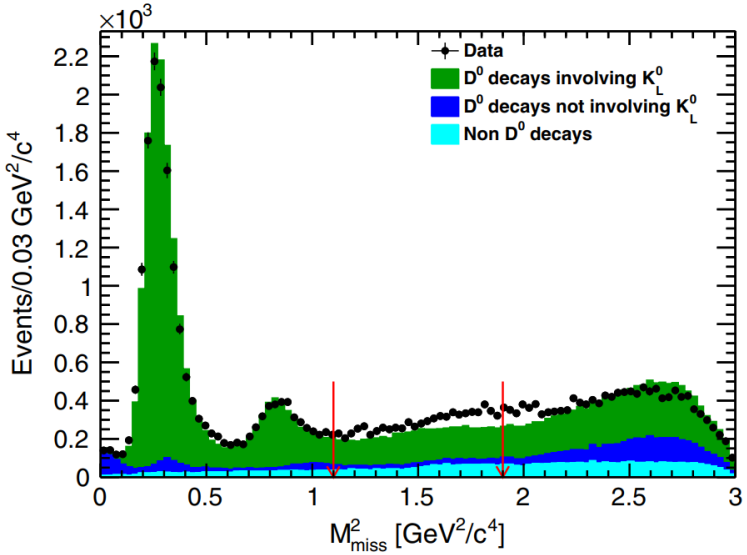


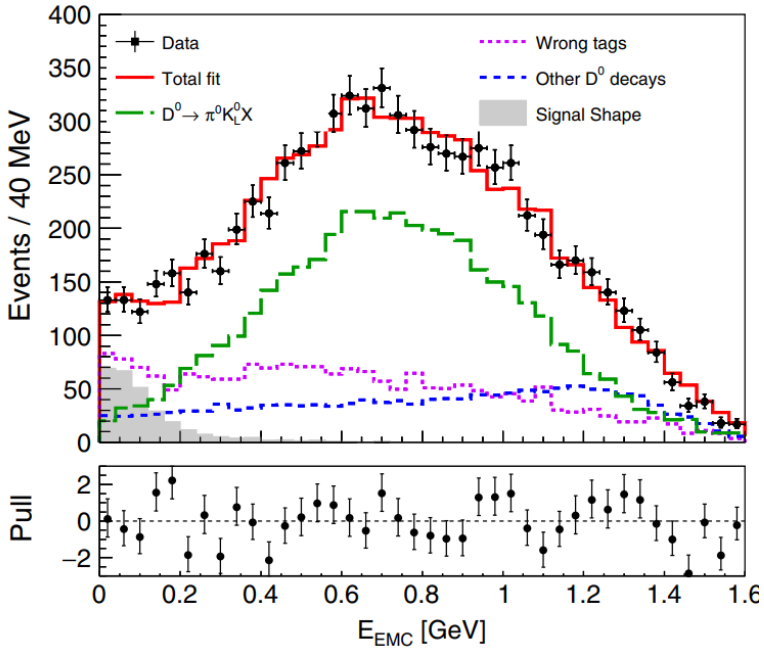
LD and SD contributions (a, c, d) to neutral D decays (a, c, d) and charged D decays (a, b, c, d).

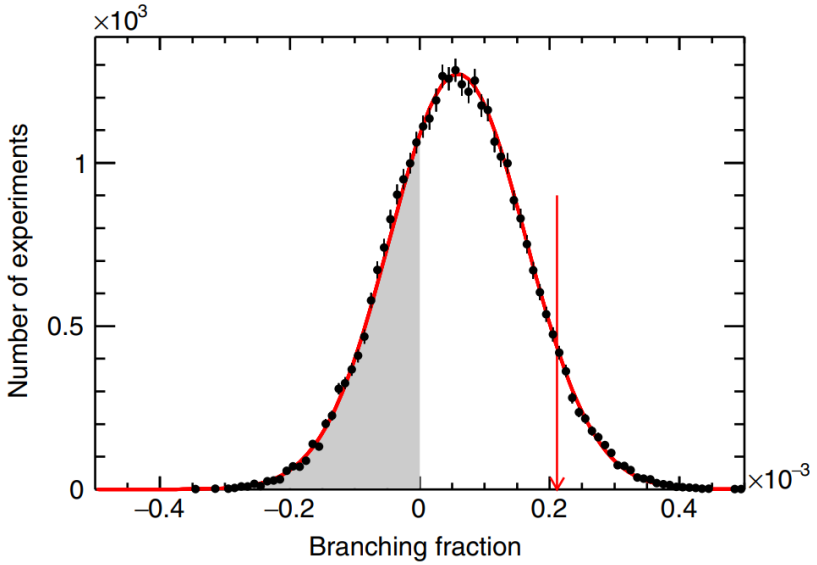
Search for $D^0 \to \pi^0 \nu\bar{\nu}$

- In the SM, FCNC is strongly suppressed by the GIM mechanism and it can happen only through loop diagram, to a very small $BF \sim 10^{-9}$.
- The suppression in charm decays is much stronger than those in B and K syste due to stronger diagram cancellation than the down-type quarks.
- Using 10.6×10^6 pairs of $D^0\bar{D}^0$ mesons.
- $M^2_{miss} = (E_D)^2/c^4 - |\vec{p}_{\pi^0}|^2/c^4$

- Discriminator: EMC energy not associated with signal and tag decays.
- $\mathcal{B}(D^0 \to \pi^0 \nu\bar{\nu}) < 2.1 \times 10^{-4}$ @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.







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Summary

- BESIII performed wide range studies 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.

BESIII

Thank you for listening.

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