Search for rare decays at BESIII

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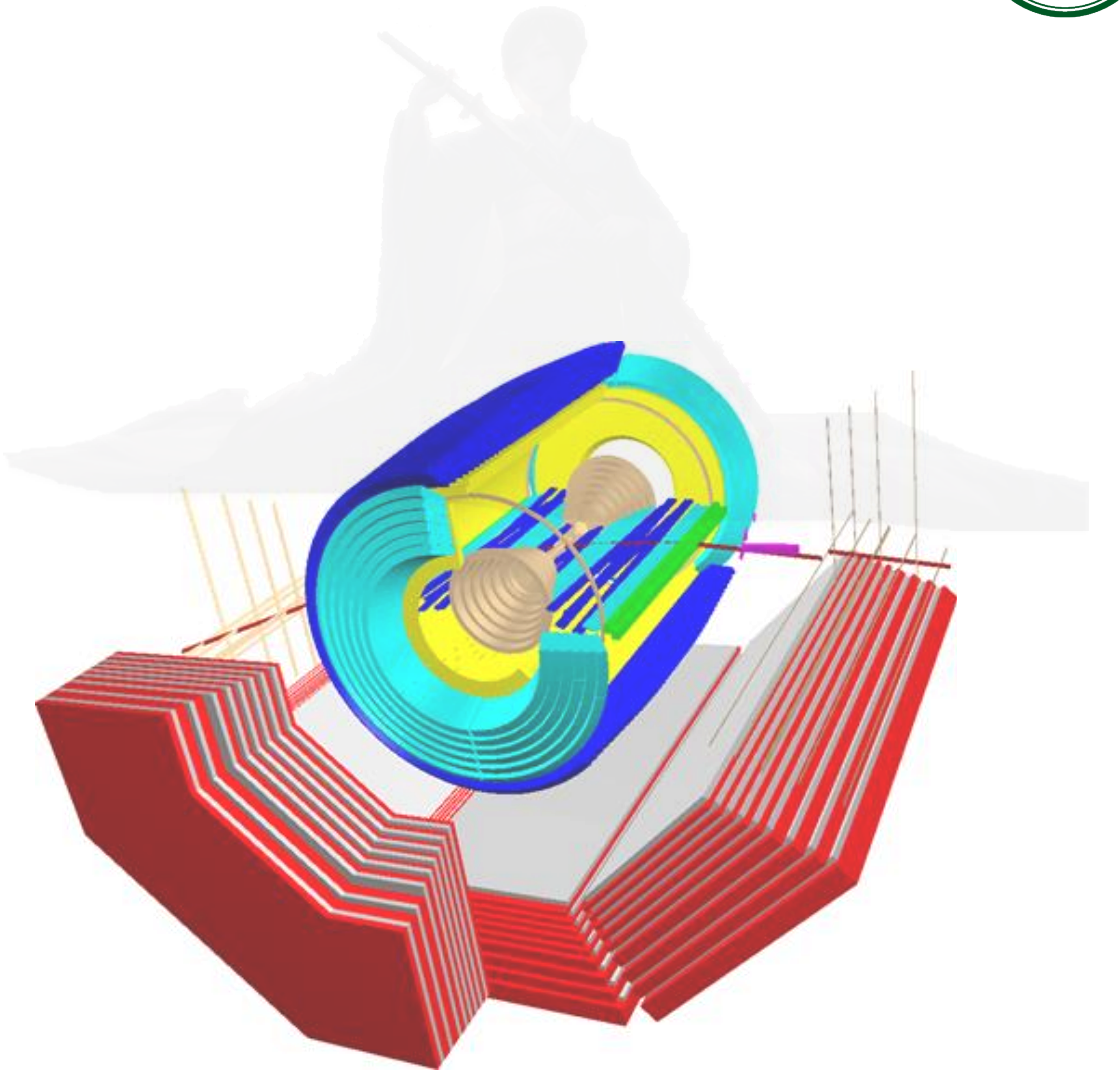
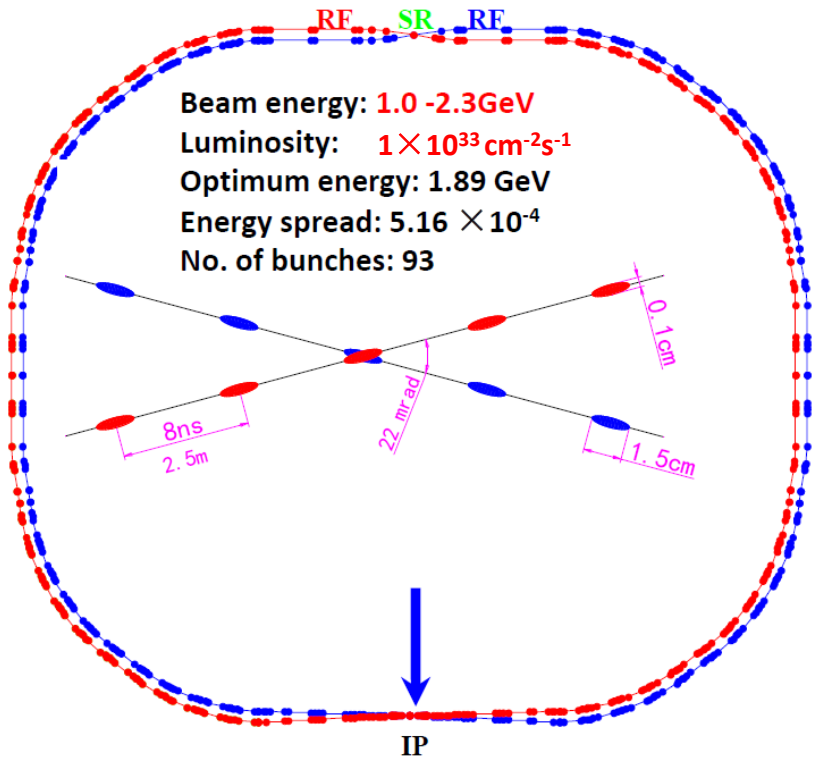
Outline

- BEPCII & BESIII
- New physics search at BESIII
- Very rare decays
  - Charmonium weak decays
  - FCNC processes
- Symmetry breaking decays
  - Baryon/Lepton Number Violation
  - Lepton Flavor Violation
- Summary



BEPCII and BESIII

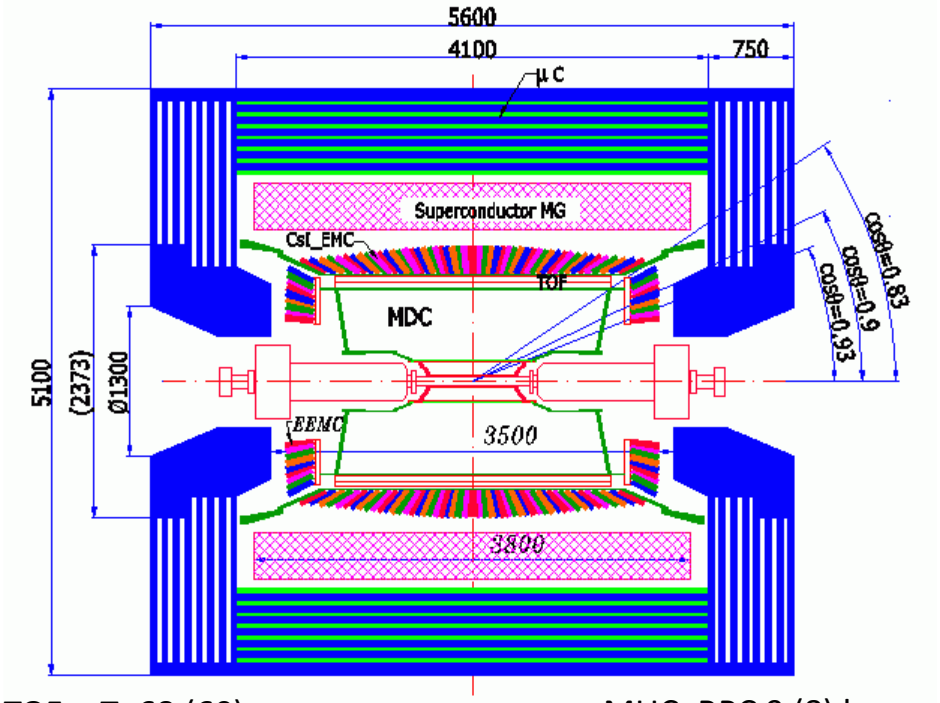
Beijing Electron Positron Collider II



BESIII Detector

MDC: Δp/p =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)

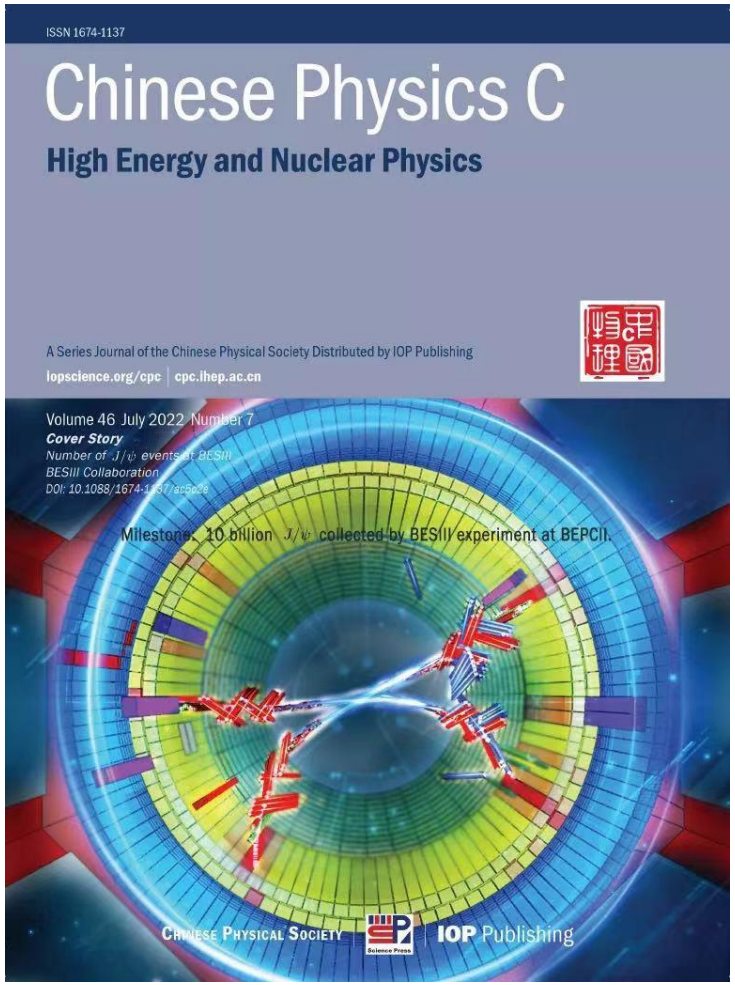
BESIII Physics Data

Physics of BESIII

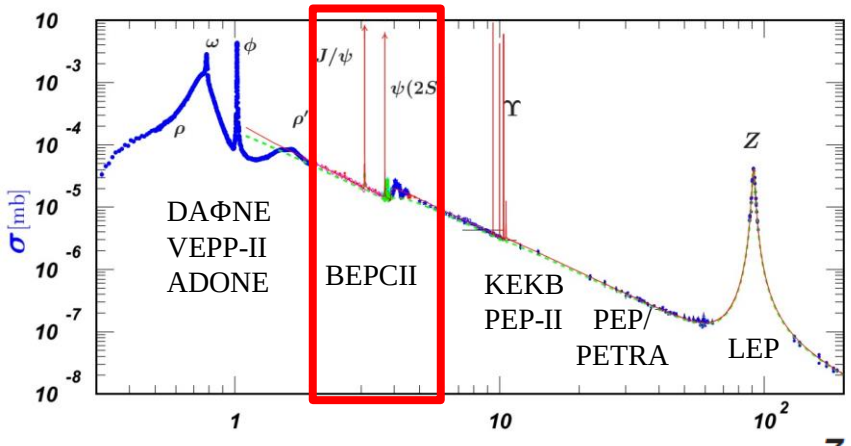
NSR 8 (11) 2021

10 Billion J/ψ collected by BESIII

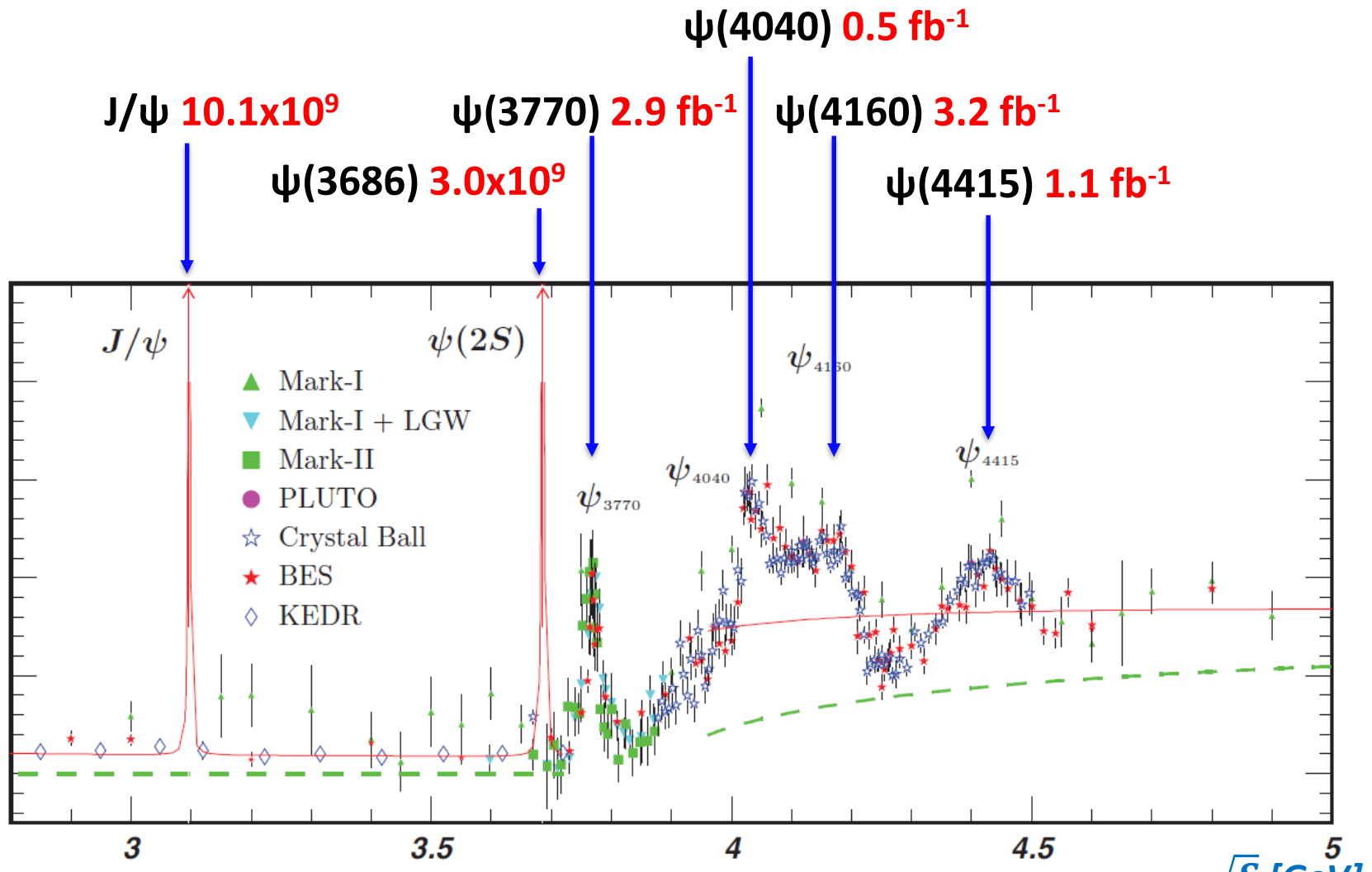
CPC 46 074001 (2022)



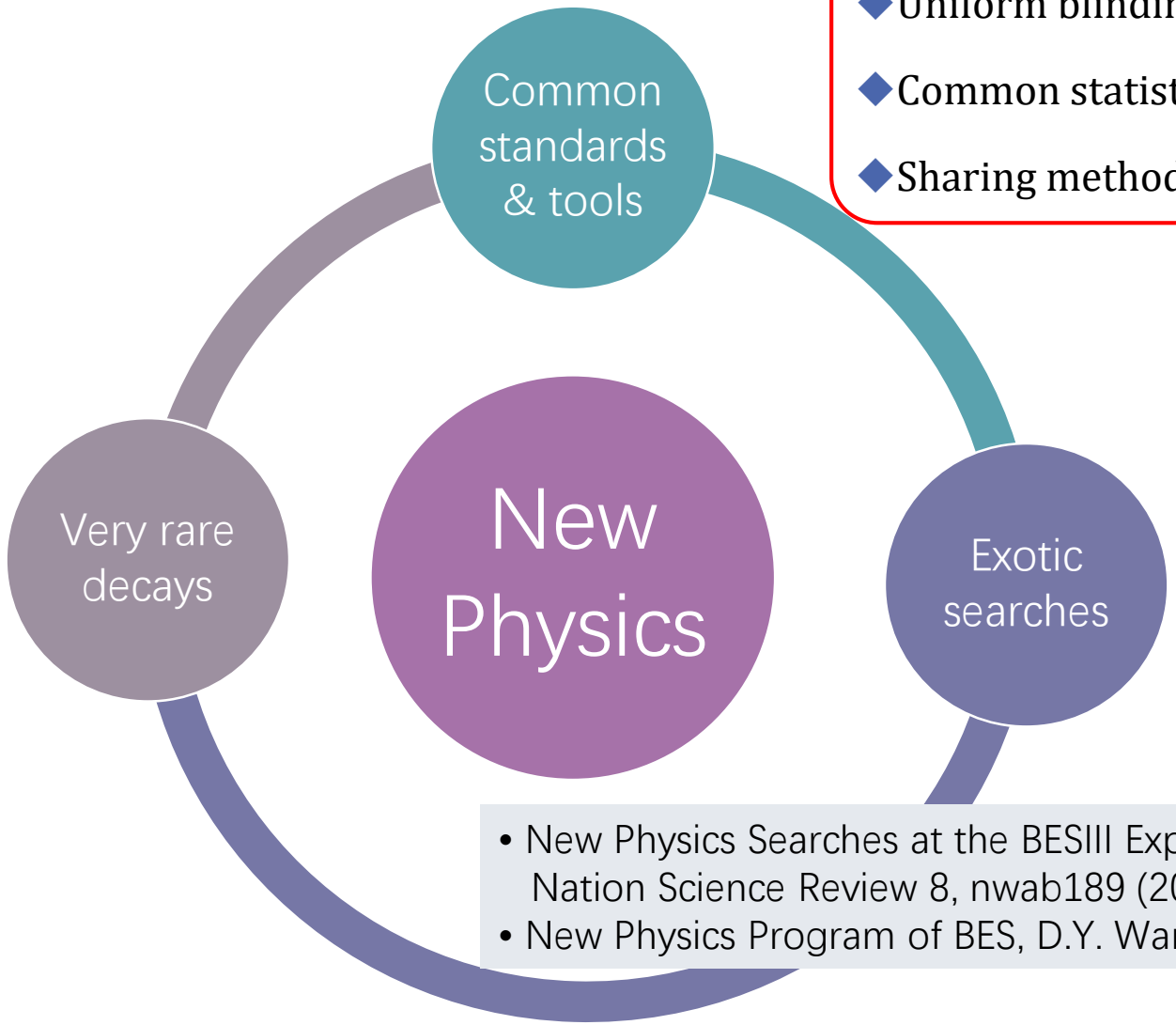
Charmonium Data at BESIII



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



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

- FCNC processes
- Charmonium weak decays
- Other rare decays

Very rare

Exotic

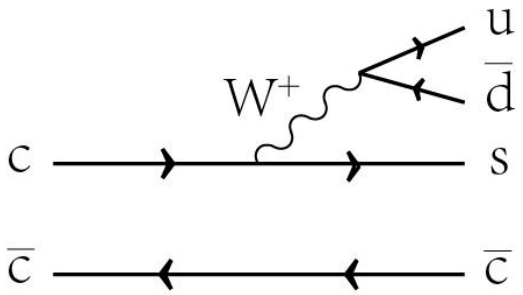
- Dark photon
- Invisible signatures
- Light Higgs, Z'
- Exotic resonances

- 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"

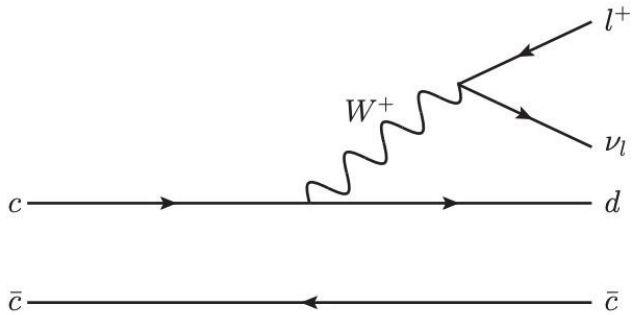
Rare decays

Charmonium weak decays

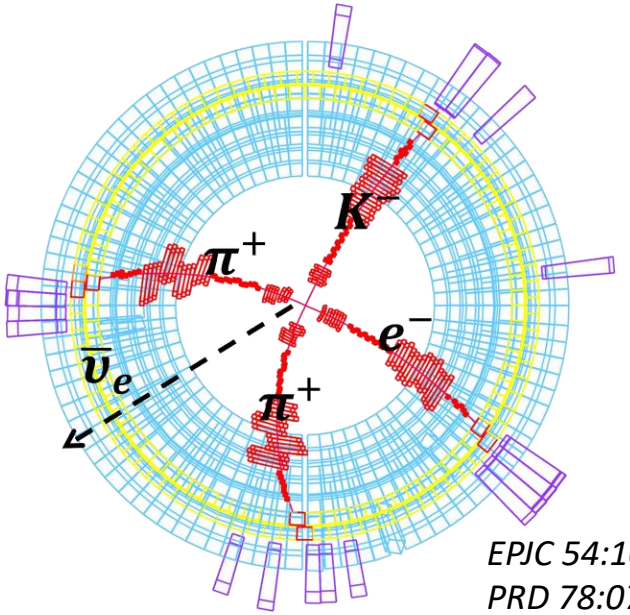
- Charmonium weak decays are **allowed in SM**, but highly suppressed by strong and EM decays
- The inclusive J/ψ weak decay branching fraction (BF) is predicted to be at the order of **10^{-8}** or lower
- Hadronic weak decays
  - $J/\psi \to D_s^{(*)-}\rho^+, J/\psi \to D^-\rho^+, J/\psi \to D_s^-\pi^+$
- Semi-leptonic weak decays
  - $J/\psi \to D_s^{(*)-}e^+\upsilon_e, J/\psi \to D^-e^+\upsilon_e, J/\psi \to D^-\mu^+\upsilon_\mu$



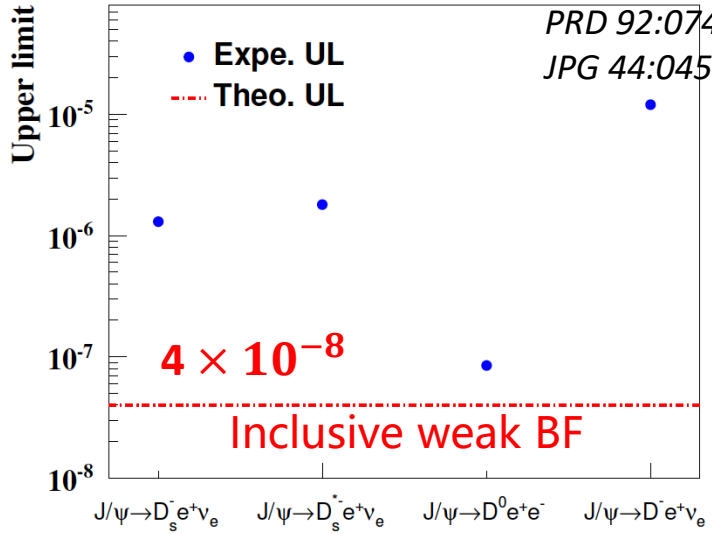
$J/\psi \to D_s^-\pi^+$



$J/\psi \to D^-e^+\upsilon_e$



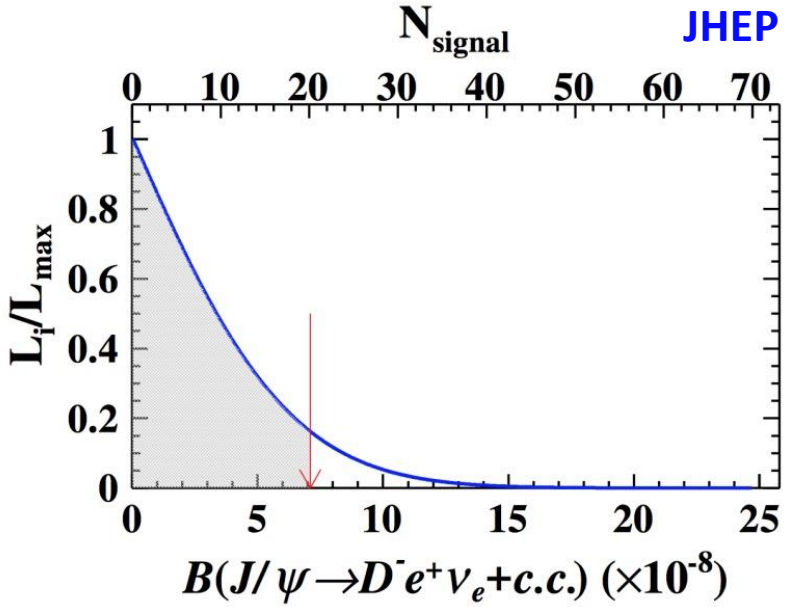
EPJC 54:107 (2008)
PRD 78:074012 (2008)
AHEP 2013:706543 (2013)
PRD 92:074030 (2015)
JPG 44:045004 (2017)

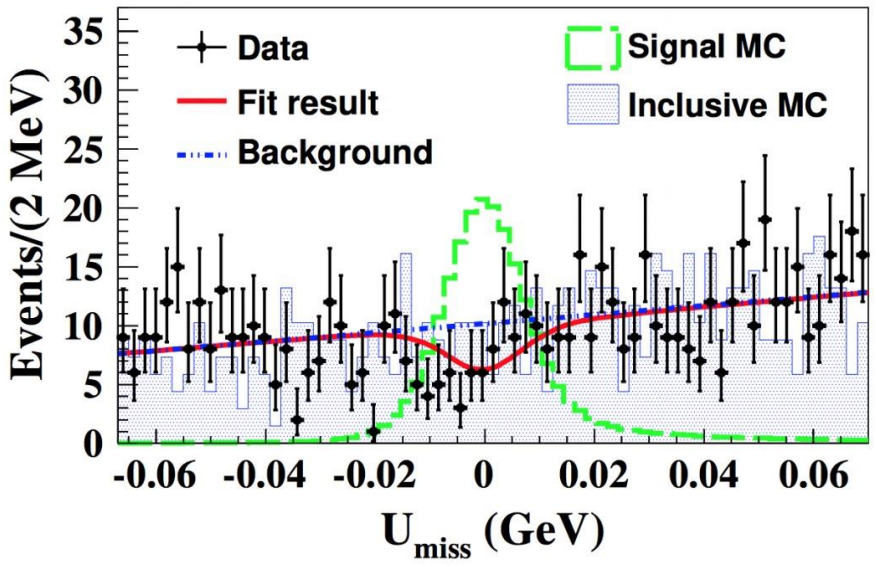


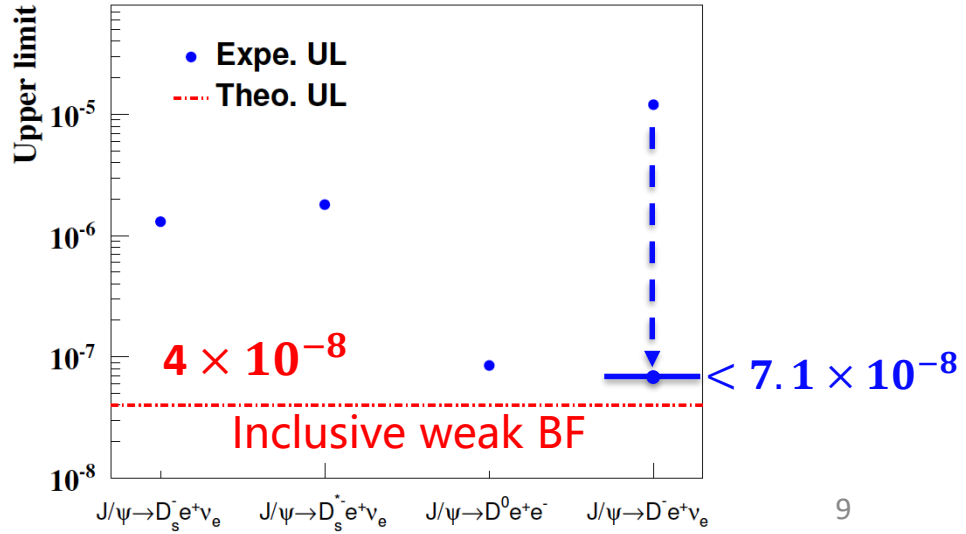
Search for charmonium weak decay $J/\Psi \to D^- e^+ \upsilon_e$

- Analyzing **10.087×10⁹ J/ψ** events
- $\mathcal{B}(J/\Psi \to D^- e^+ \bar{\nu}_e) < 7.1 \times 10^{-8}$ @ **90%C. L.**
- The upper Limit (UL) is improved by more than two orders of magnitude
- The result is compatible with theory prediction and approaching the inclusive BF limit.

JHEP 157 (2021)

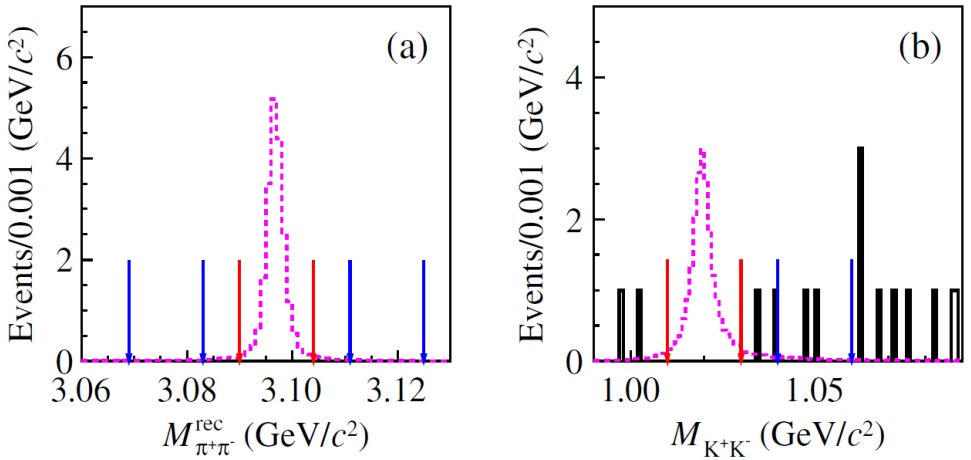




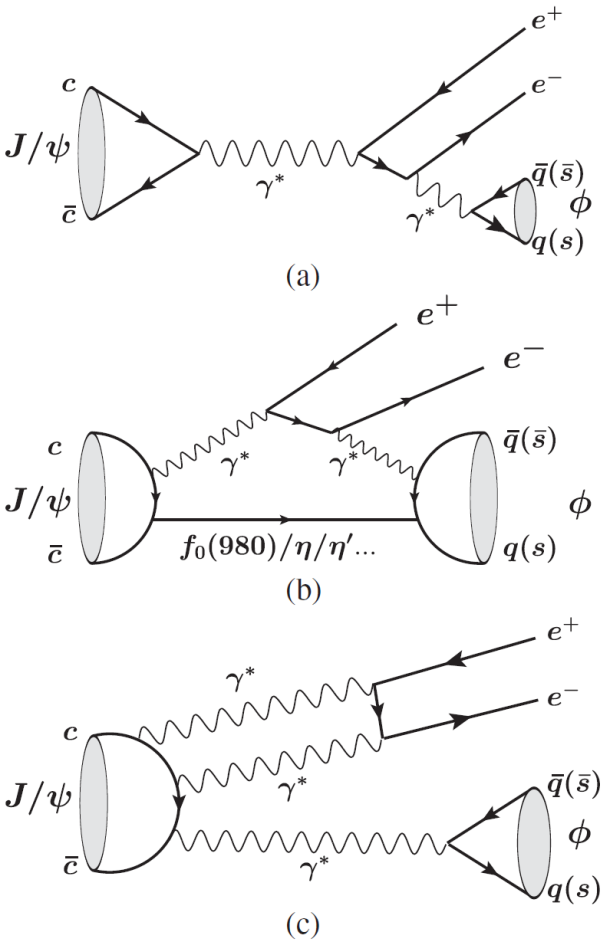


Search for rare decay $J/\Psi \to \phi e^+ e^-$

- In SM, $J/\Psi \to \phi e^+ e^-$ is predicted to be at the order of **10^{-8} ~ 10^{-11}**
- Mainly decay through 3 dynamic processes
- New particles (dark γ / glueball) could enhance the contribution (b) to an observable level
- Analyzing **448.1×10^6 ψ(3686)** events
- Background free with $\Psi(3686) \to \pi^+\pi^- J/\Psi$
- $\mathcal{B}(J/\Psi \to \phi e^+ e^-) < 1.2 \times 10^{-7}$ @ **90%C.L.**



PRD 99 052010 (2019)



(a) the leading-order EM process

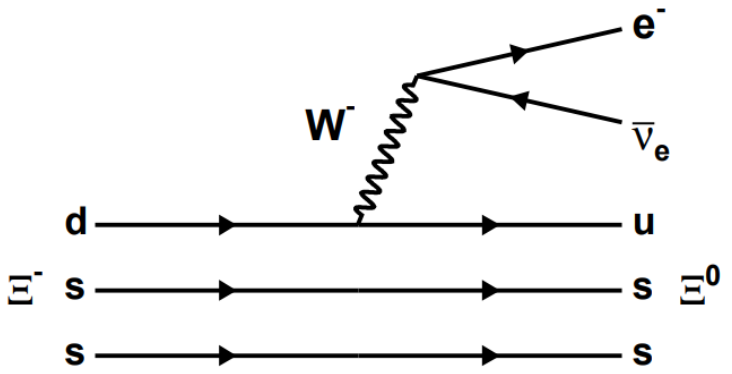
(b) the EM and strong mixed loop process

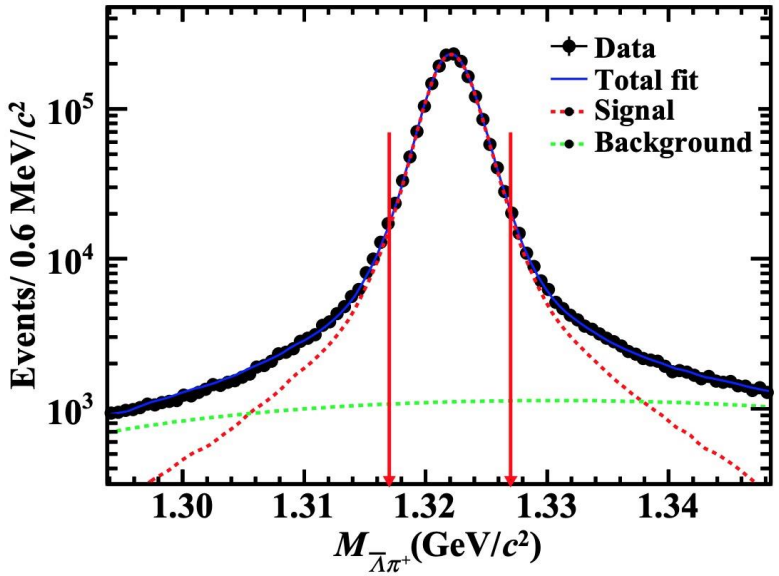
(c) the EM process proceeding through three virtual photons

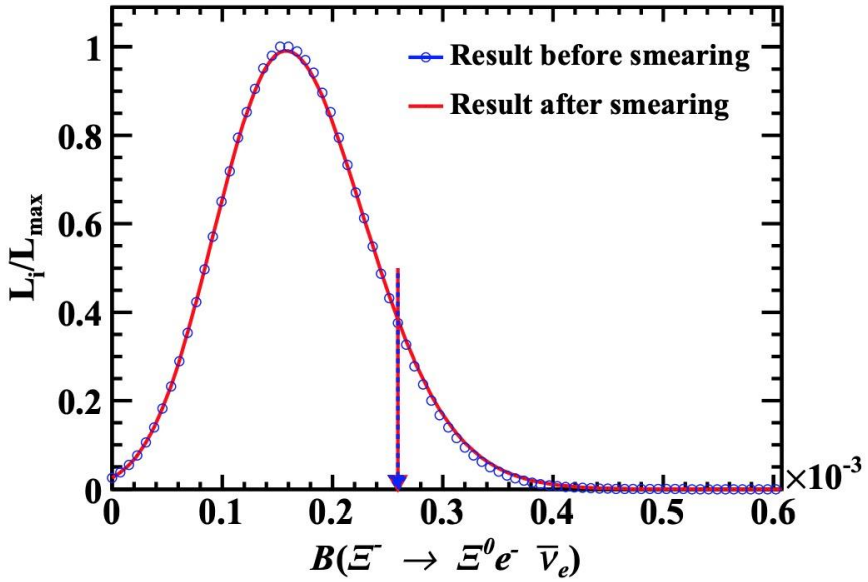
Search for hyperon semi-leptonic decay $\Xi^- \to \Xi^0 e^- \bar{\nu}_e$

PRD 104 072007 (2021)

- Provide important information on the interplay between weak interactions and hadronic structures formed through strong interactions
- Analyzing **10.087×10⁹ J/ψ** events
- $\mathcal{B}(\Xi^- \to \Xi^0 e^- \bar{\nu}_e) < 2.59 \times 10^{-4}$ @ **90%C. L.**
- One order of magnitude more strict than before



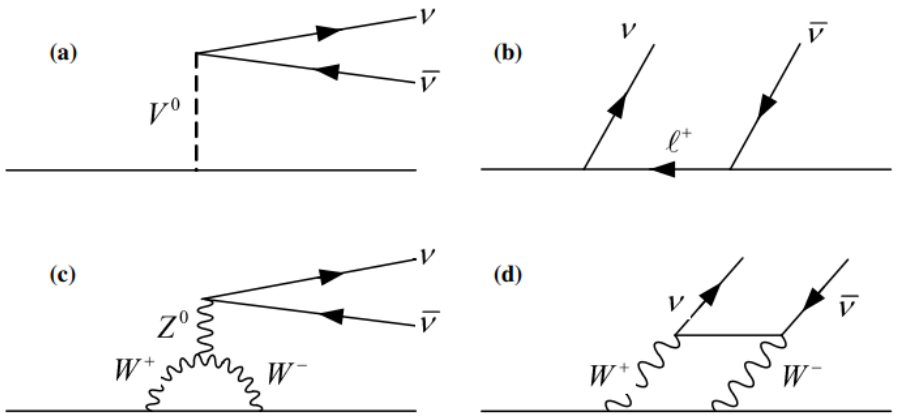


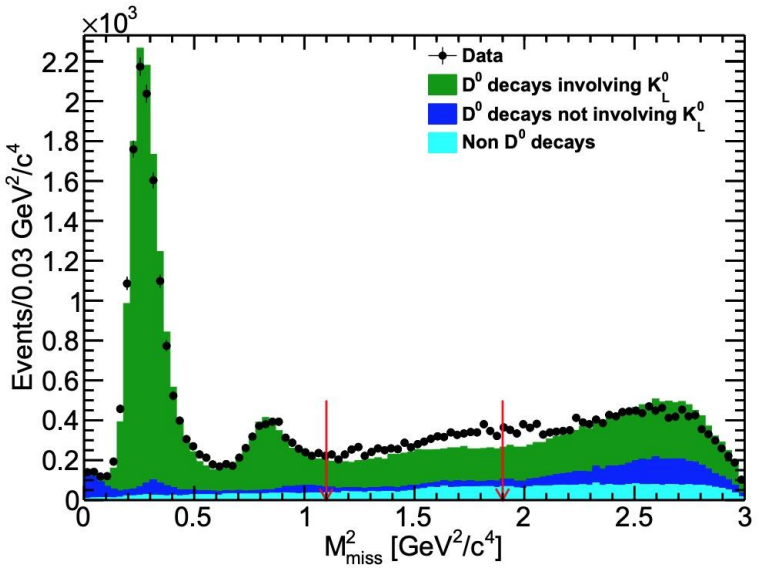


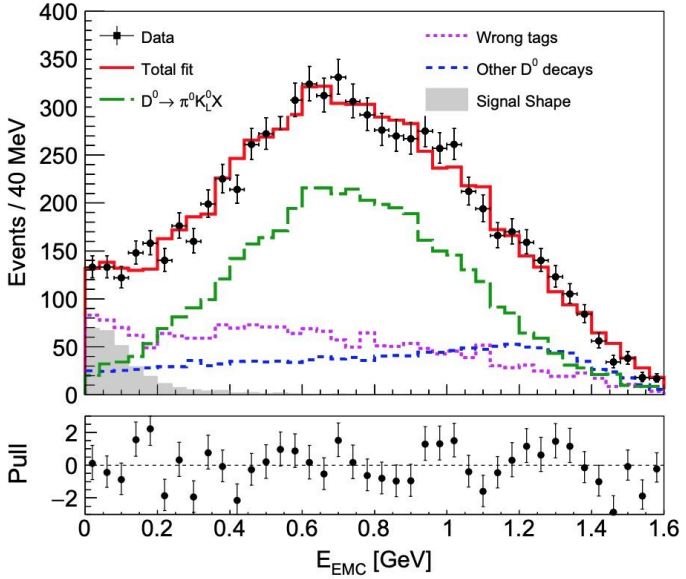
Search for FCNC process $D^0 \to \pi^0 \nu \bar{\nu}$

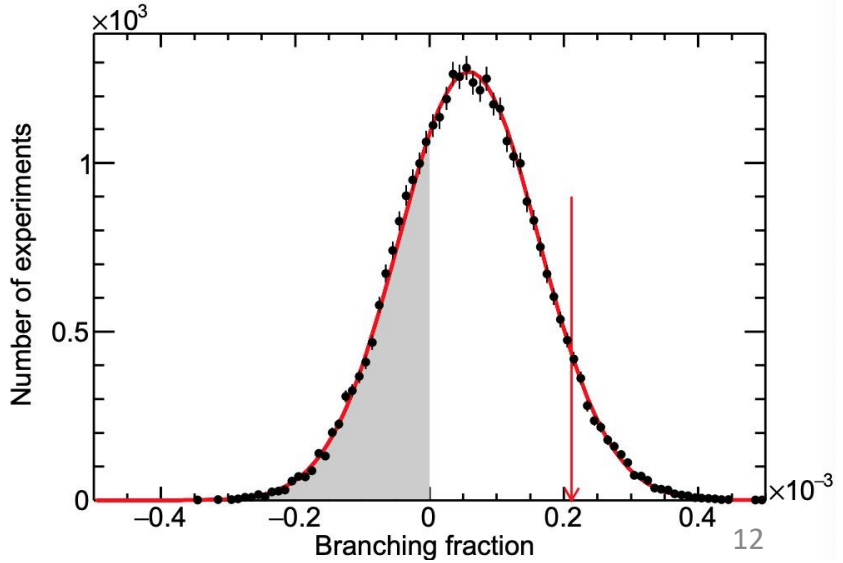
- In SM, FCNC is highly suppressed by GIM mechanism, only through loop diagram, a very small BF **10^{-9} ~10^{-15}**
- The suppression in charm decay is much stronger than B & K system, stronger diagram cancellation
- Analyzing **10.6×10^6** $D^0\bar{D}^0$ pairs
- $\mathcal{B}(D^0 \to \pi^0 \nu \bar{\nu}) < 2.1 \times 10^{-4}$ @ **90% C. L.**
- The first constraint on charmed hadron to di-neutrino

PRD 105 L071102 (2022)





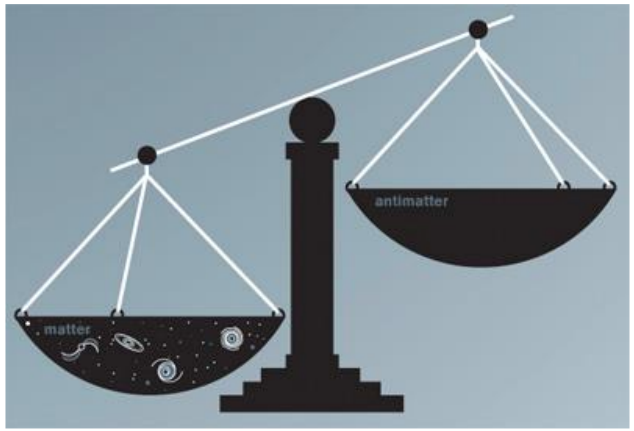




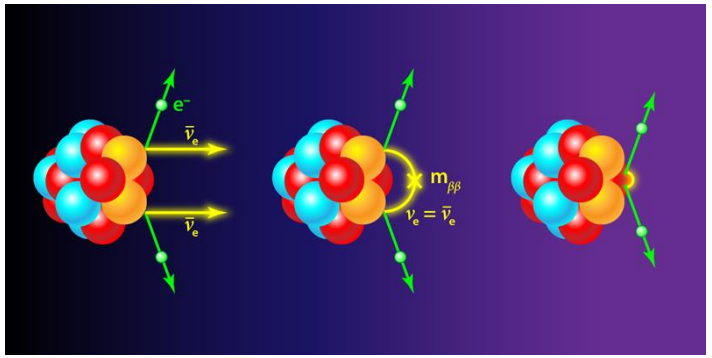
BNV LNV

Baryon / Lepton Number Violation

- In the Standard Model, baryon number is conserved
- However, baryon anti-baryon number is highly asymmetric in the universe
- BNV is allowed in GUT and SM extensions $\Delta(B-L)=0$
- Furthermore, another BNV under dimension seven operators allow $\Delta(B-L)=2$



- Lepton Number Violation processes can be used to test the nature of neutrino, Dirac or Majorana?
- Neutrinoless double beta decay is the most promising
- LNV can also be probed with hadron/lepton decays

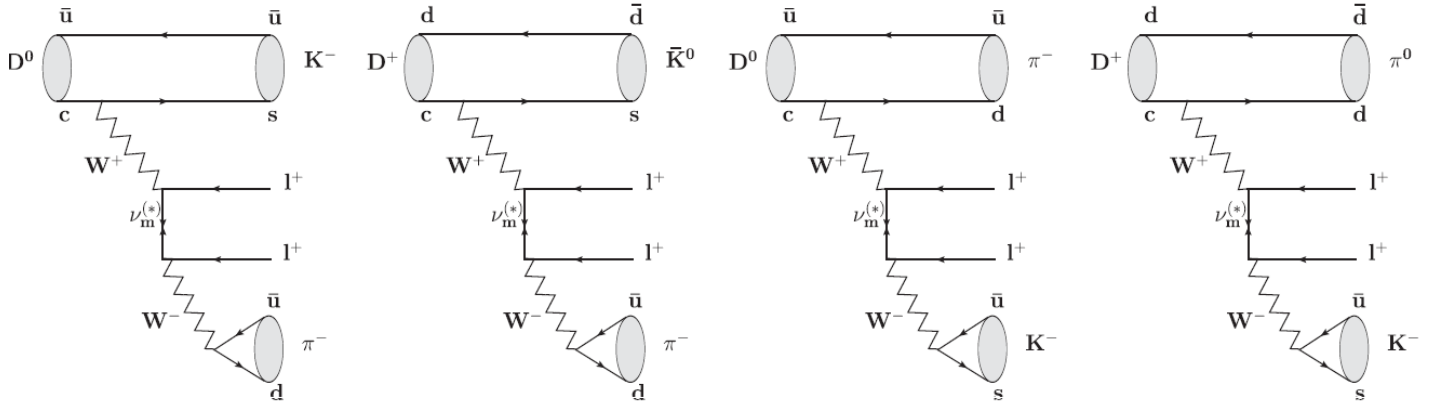


PRD 22 1694 (1980)
PRD 101 015017 (2020)
PRD 72 095001 (2005)
PRD 59 091303 (1999)
JHEP 05 030 (2009)
PRL 120 132501 (2018)
PRD 93 094026 (2016)
JHEP 08 068 (2011)

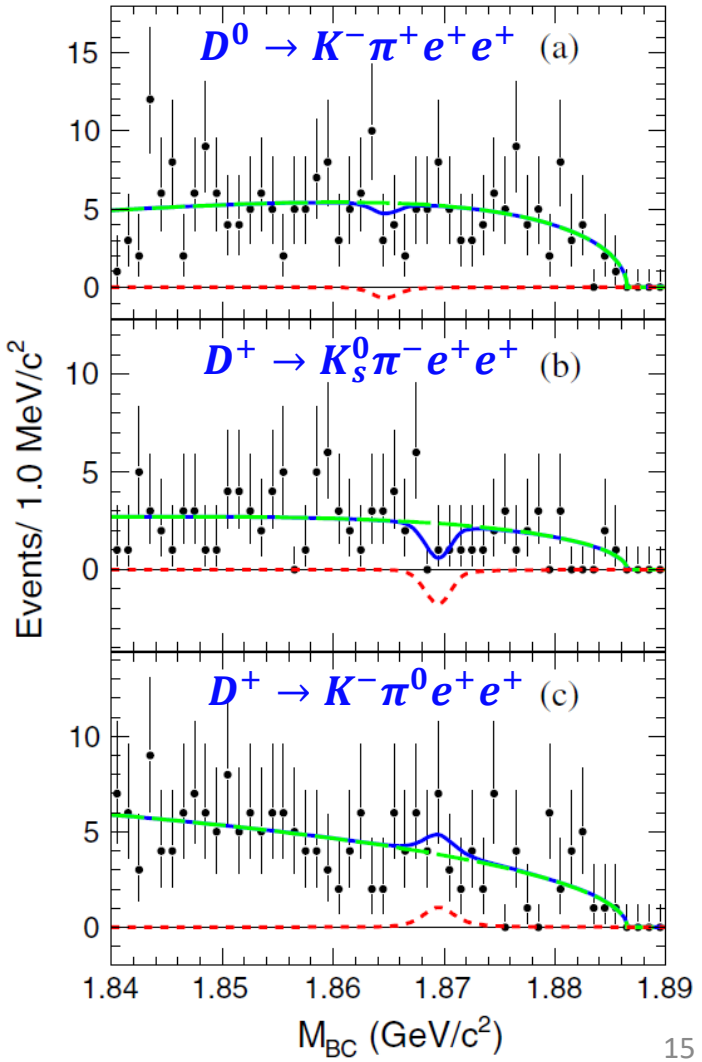
Search for LNV decay $D \to K\pi e^+e^+$

- Analyzing **2.93 fb^{-1} 3.773 GeV** data $(B-L)$ *violated*
- $\mathcal{B}(D^0 \to K^-\pi^+e^+e^+) < 2.8\times10^{-6}$ @ 90%C. L.
- $\mathcal{B}(D^+ \to K^0_S\pi^-e^+e^+) < 3.3\times10^{-6}$ @ 90%C. L.
- $\mathcal{B}(D^+ \to K^-\pi^0e^+e^+) < 8.5\times10^{-6}$ @ 90%C. L.
- The theoretical UL of BF is at the level of **10^{-7} ~ 10^{-6}**
- Majorana neutrino is searched for with different mass assumptions in [0.25, 1.0] GeV/c^2

PRD 99 112002 (2019)



(a) $D^0 \to K^-\pi^-l^+l^+$ (CF) (b) $D^+ \to \bar{K}^0\pi^-l^+l^+$ (CF) (c) $D^0 \to K^-\pi^-l^+l^+$ (DCS) (d) $D^+ \to K^-\pi^0l^+l^+$ (DCS)

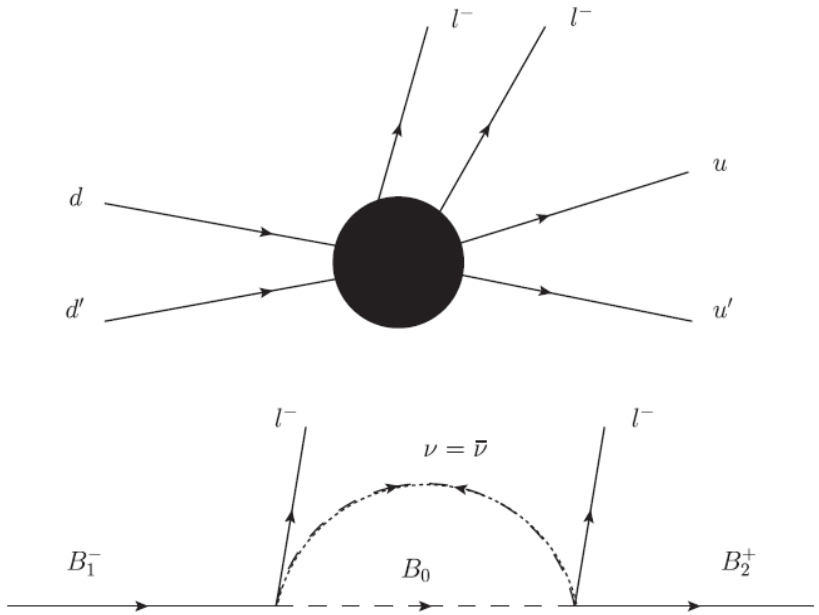


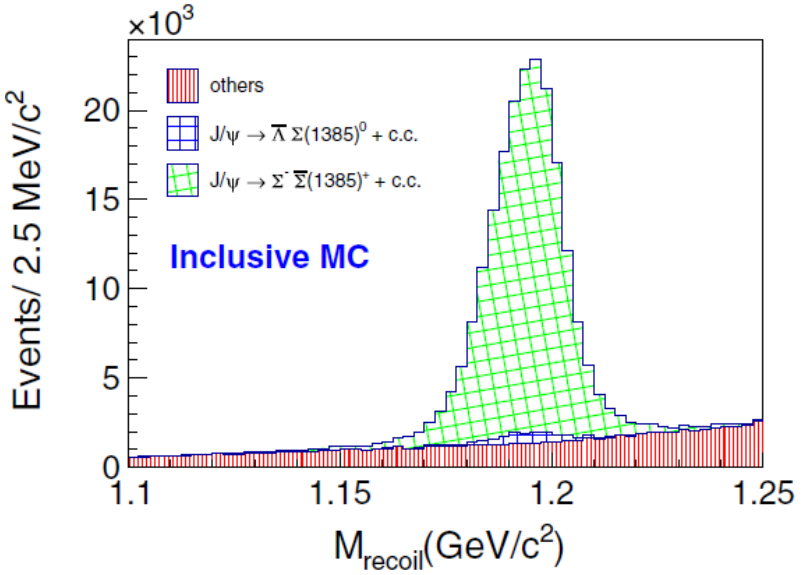
Search for LNV decay $\Sigma^- \to p e^- e^-, \Sigma^- \to \Sigma^+ X$

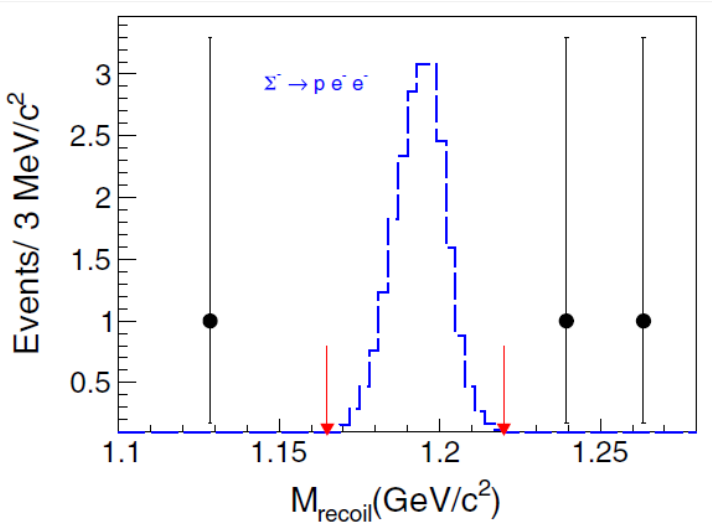
- Analyzing **1.310×10⁹ J/ψ** events
- $\mathcal{B}(\Sigma^- \to p e^- e^-) < 6.7 \times 10^{-5}$ @ **90%C. L.**
- $\mathcal{B}(\Sigma^- \to \Sigma^+ + X) < 1.2 \times 10^{-4}$ @ **90%C. L.**
- Double tag method $J/\Psi \to \bar{\Sigma}(1385)^+ \Sigma^-$
- Search for Majorana neutrino, well above limit

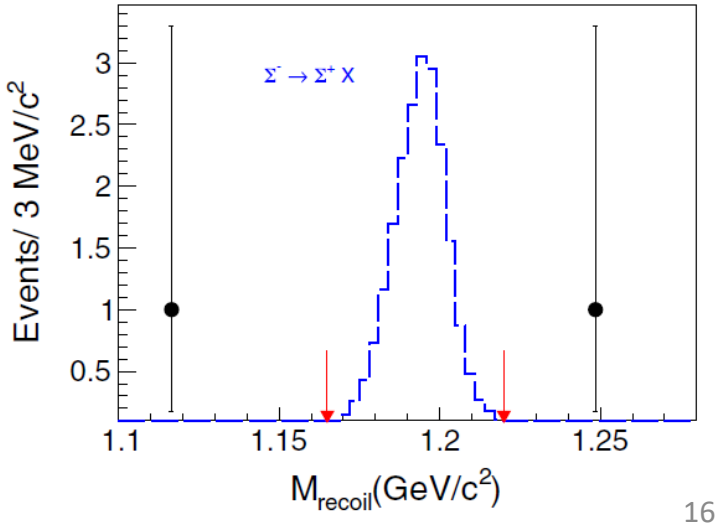
$(B - L)$ *violated*

PRD 103 052011 (2021)







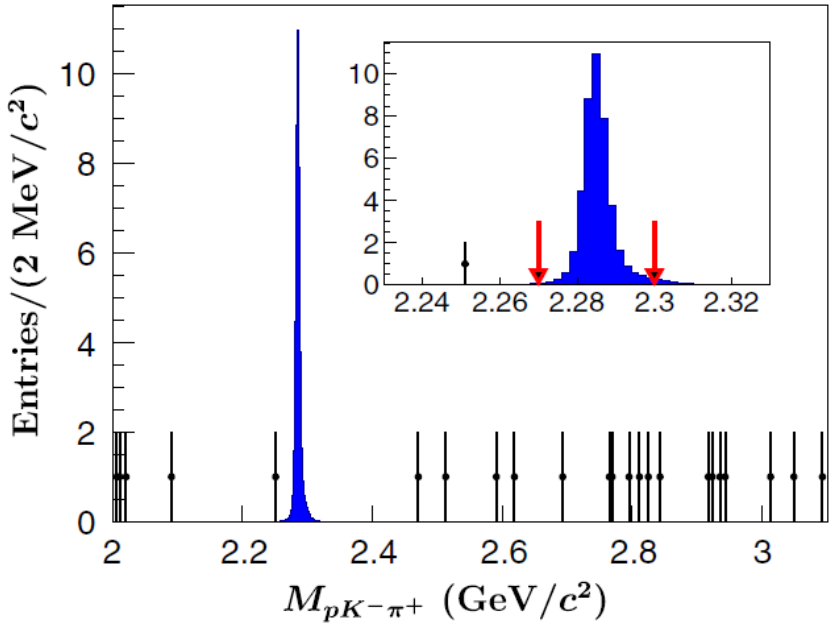


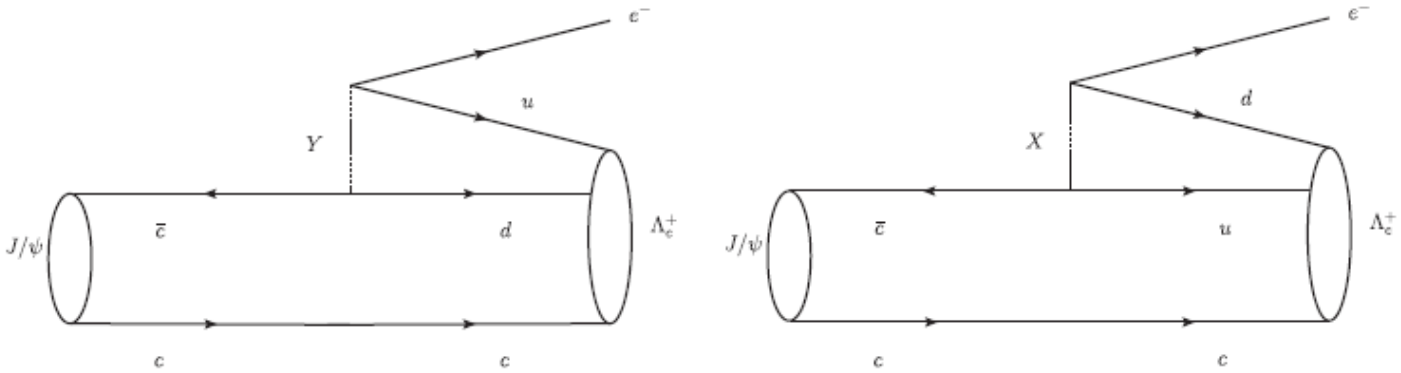
Search for LNV & BNV decay $J/\psi \to \Lambda_c^+ e^-$

- Both lepton and baryon number violated
- Matter anti-matter asymmetry
- Analyzing **1.310×10⁹ J/ψ** events
- Look for signal in mass of $pK\pi$ combination
- $\mathcal{B}(J/\psi \to \Lambda_c e^-) < 6.9 \times 10^{-8}$ @ **90%C. L.**
- Two orders of magnitude more strict than CLEO
- One of the best constraints from meson decay

PRD 99 072006 (2019)

$(B - L)$ *conserved*



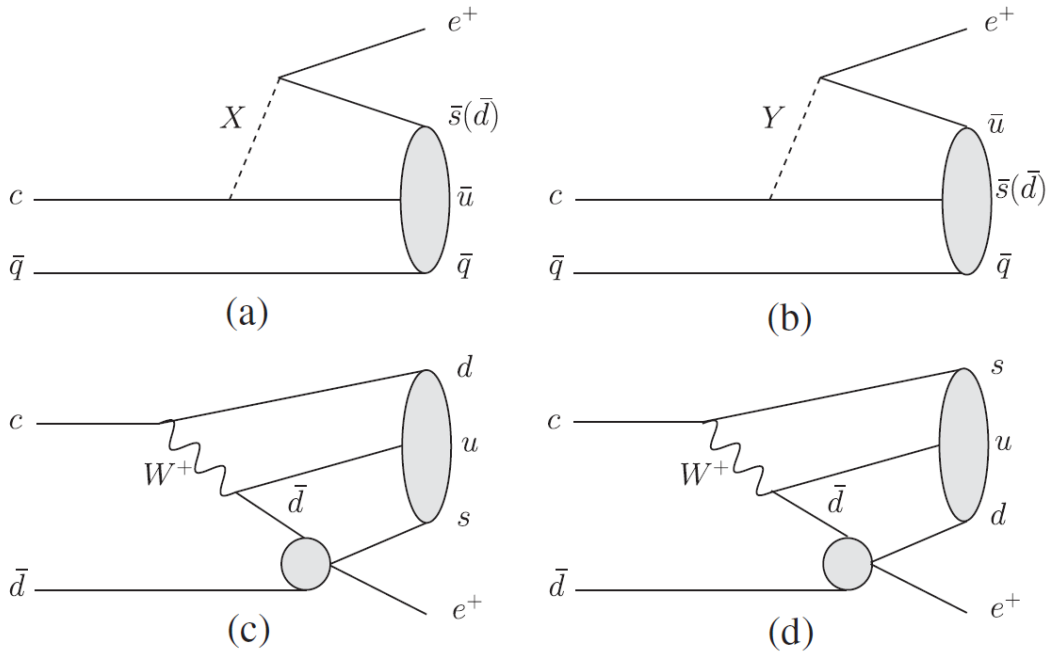


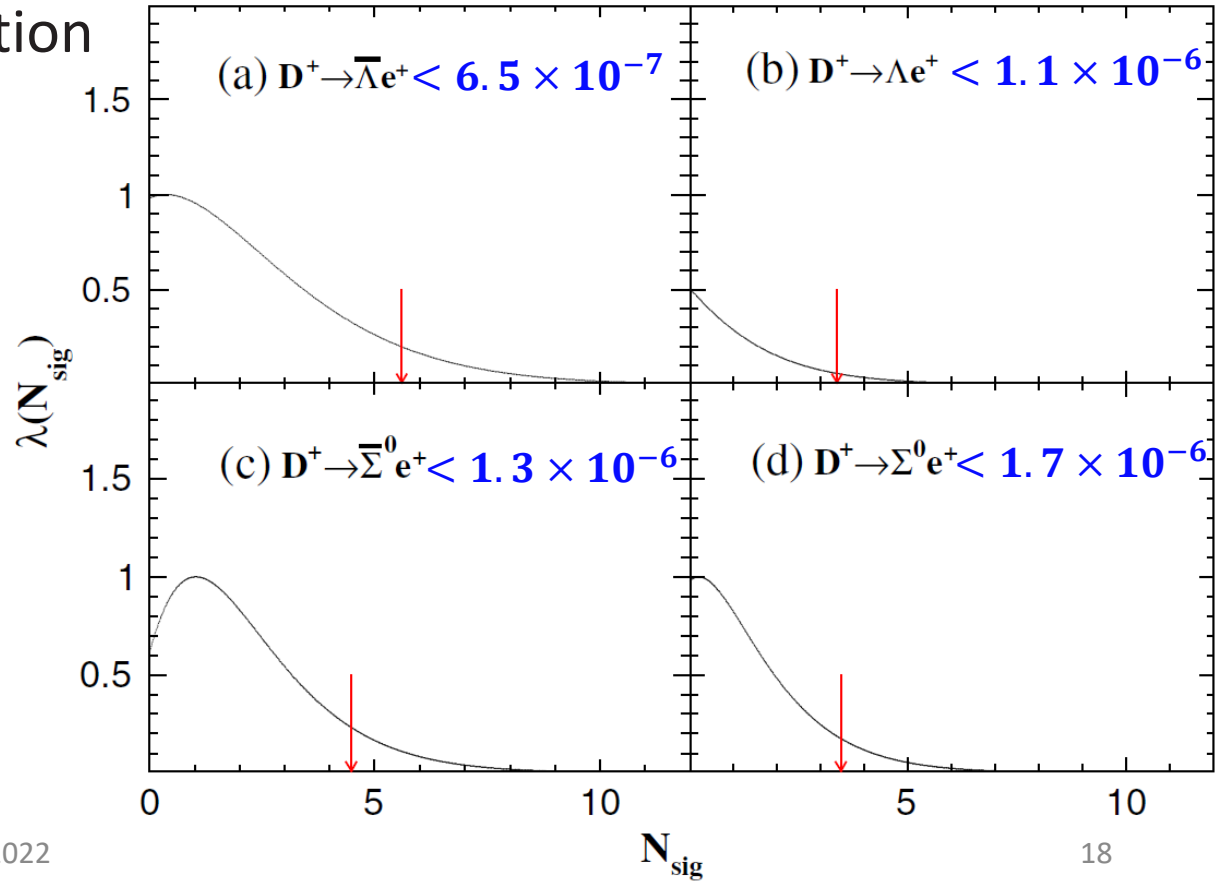
Search for LNV & BNV decay $D^+ \to \bar{\Lambda}(\bar{\Sigma}^0)e^+$

- Prediction of $\mathcal{B}(D^+ \to \bar{\Lambda} l^+) < 10^{-29}$
- Analyzing **2.93 fb^{-1} 3.773 GeV** data
- ULs of BF measured at the level of 10^{-6} @ **90%C. L.**
- Far above higher generation model prediction

PRD 101 031102(R) (2020)

$\Delta(B-L)=0$ $\Delta(B-L)=2$

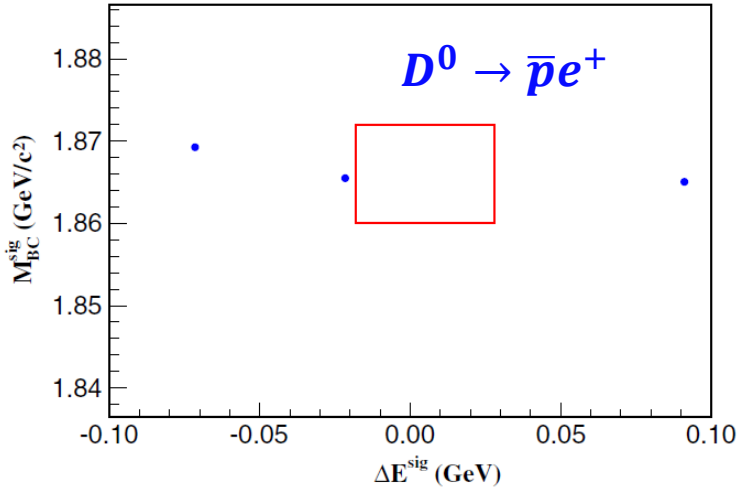


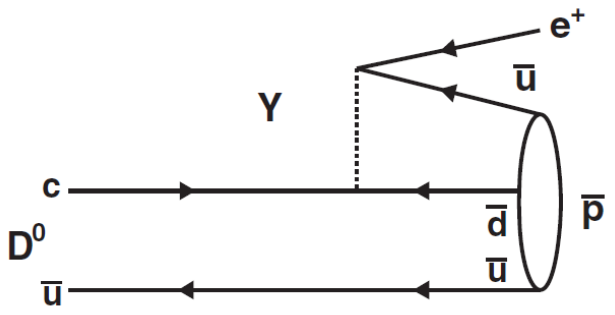


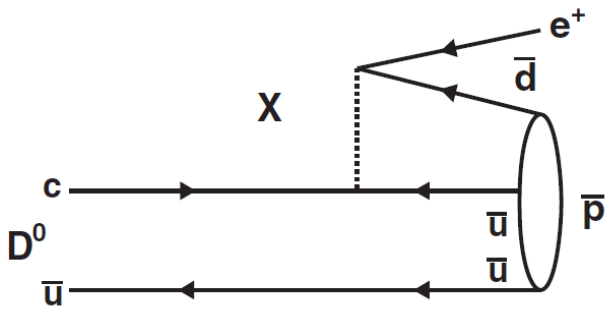
Search for LNV & BNV decay $D^0 \to pe^-$

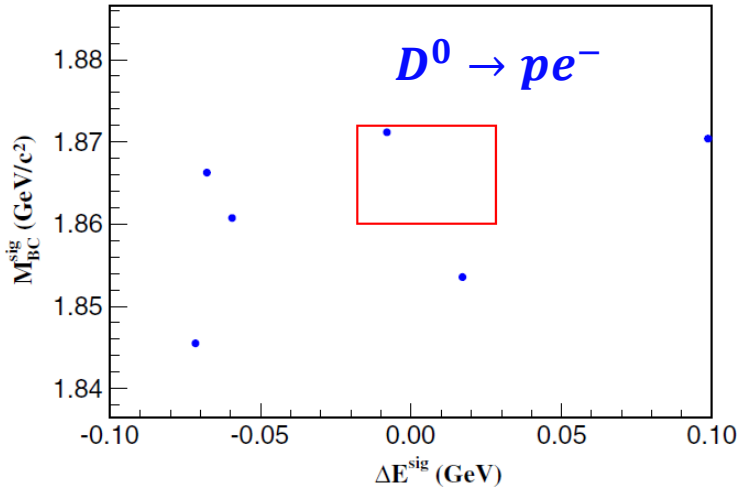
- BNV can happen with $\Delta(B-L)=0$ at dimension-six operators
- With $\Delta(B-L)=2$ allowed at dimension-seven operators
- Analyzing **2.93 fb^{-1} 3.773 GeV** data
- $\mathcal{B}(D^0 \to \bar{p}e^+) < 1.2 \times 10^{-6}$ @ **90%C. L.**
- $\mathcal{B}(D^0 \to pe^-) < 2.2 \times 10^{-6}$ @ **90%C. L.**
- The most stringent ones to date for these processes
- Still far above higher generation model prediction

PRD 105 032006 (2022)







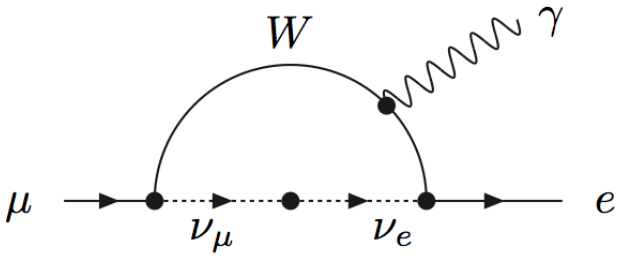


LFV

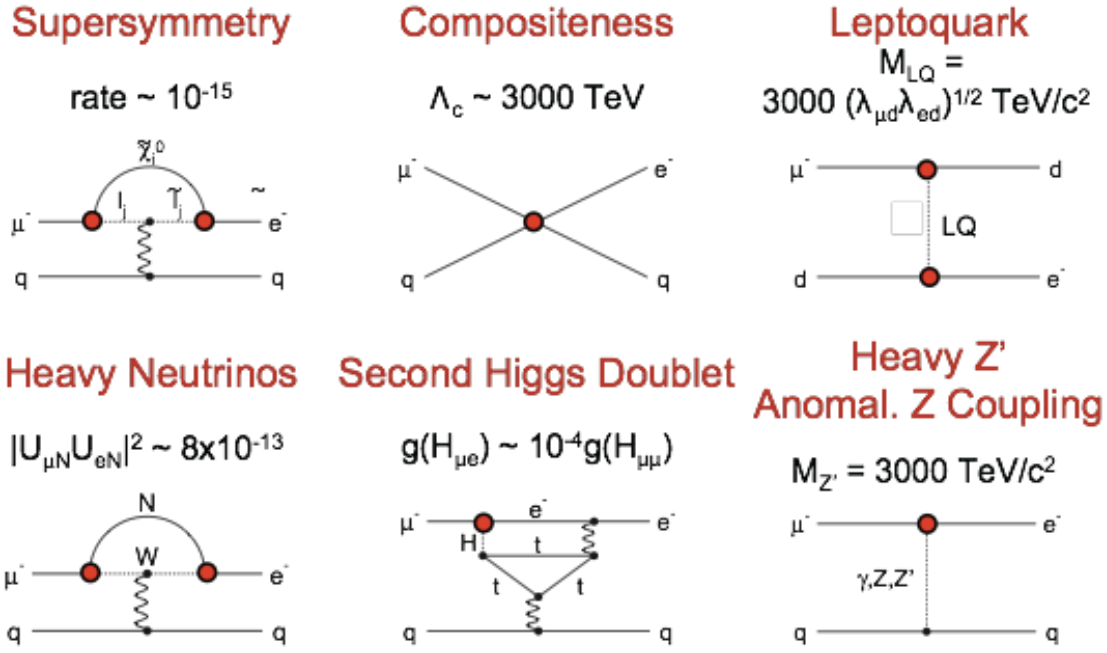
Lepton Flavor Violation

- With neutrino mixing, LFV is allowed in extended SM, but too small to be detectable

$$BR(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i}U_{ei}\frac{\Delta m^2_{1i}}{M_W^2}\right|^2 < 10^{-54}$$



- New Physics models predict
  - $\mathcal{B}(J/\psi \to e\mu) \sim 10^{-16}\sim10^{-9}$
  - $\mathcal{B}(J/\psi \to e\tau(\mu\tau)) \sim 10^{-10}\sim10^{-8}$
  - Model-independent prediction [1, 2]
  - Rotating mass matrix [3]
  - Unparticle physics [4]
  - Effective Lagrangian [5]
  - MSSM with gauged baryon and lepton number [6]



[1] X. M. Zhang et al, Phys. Rev. D 63, 016003 (2000).
[2] T. Gutche et al, Phys. Rev. D 83, 115015 (2011).
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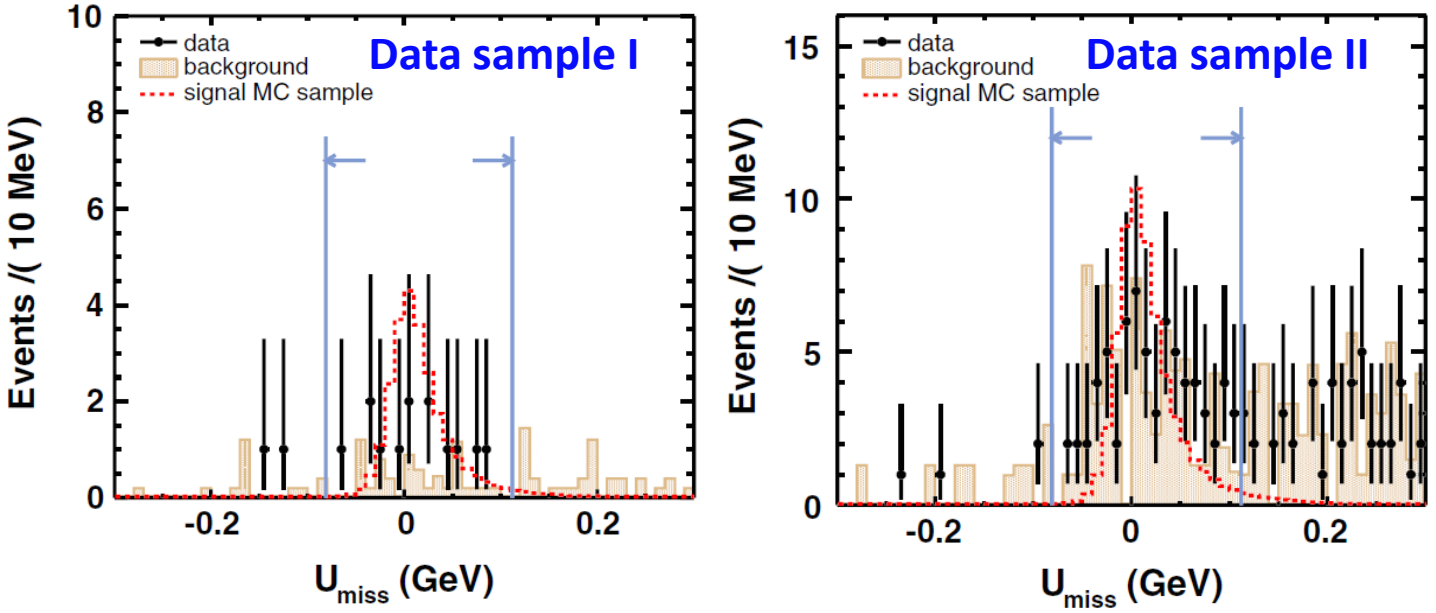
[4] K. S. Sun et al, Mod. Phys. Lett. A 27, 1250172 (2012).
[5] D. E. Hazard and A. A. Petrov, Phys. Rev. D 94, 074023 (2016).
[6] X. X. Dong et al, Phys. Rev. D 97, 056027 (2018).

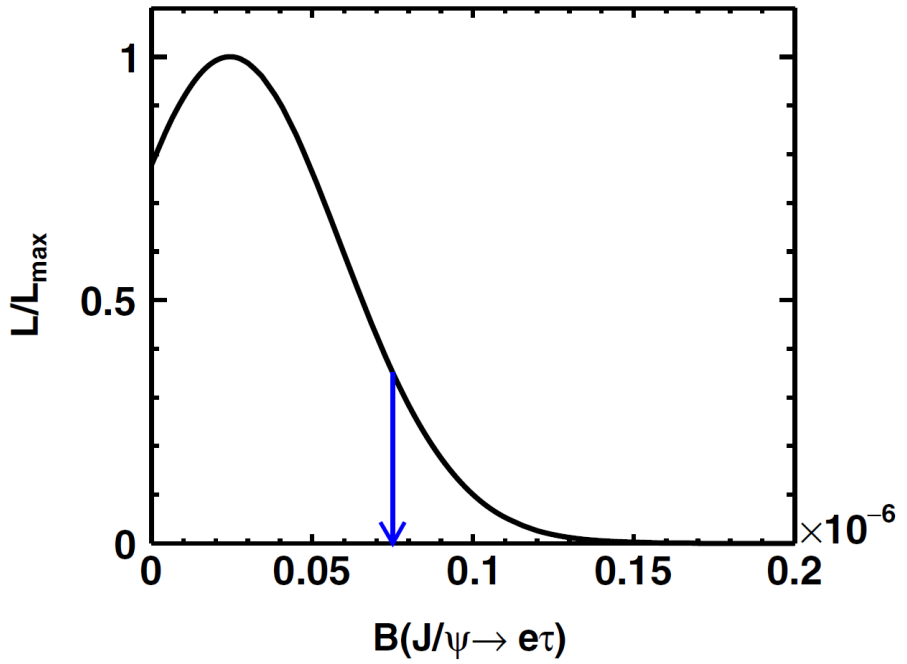
Search for LFV decay $J/\psi \to e^{\pm}\tau^{\mp}$

- Analyzing **10.087×10⁹ J/ψ** events
- Two data samples: 2009+2012 (I), 2017-2019 (II)
- Searching process $J/\psi \to e\tau, \tau \to \pi\pi^0\nu$
- $\mathcal{B}(J/\psi \to e\tau) < 7.5 \times 10^{-8}$ @ **90%C. L.**
- Improve the previous best limits by two orders of magnitude, comparable with theoretical predictions

PRD 103 112007 (2021)

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



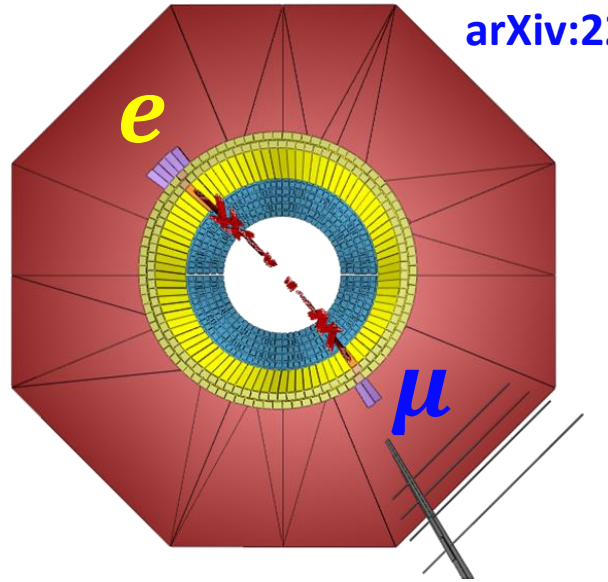


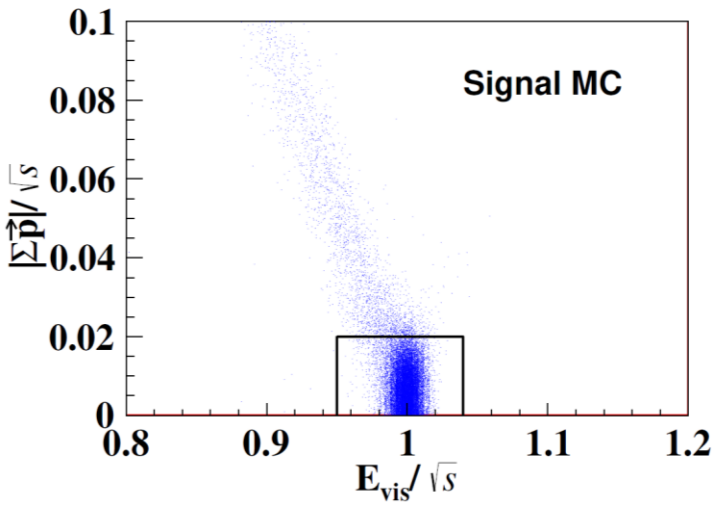
Search for LFV decay $J/\psi \to e^{\pm}\mu^{\mp}$

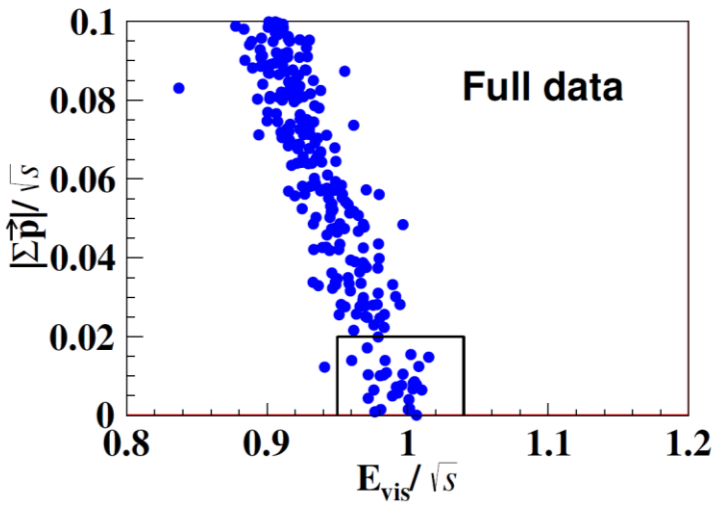
- Analyzing **8.998×10⁹ J/ψ** events
- Searching for two back-to-back $e\ \mu$
- $\mathcal{B}(J/\psi \to e\mu) < 4.5 \times 10^{-9}$ @ **90%C. L.**
- Improve the previous best limit by a factor of > 30
- The most stringent BESIII upper limit measurement
- The most precise CLFV search in heavy quarkonium
- Excluding the parameter space of some models

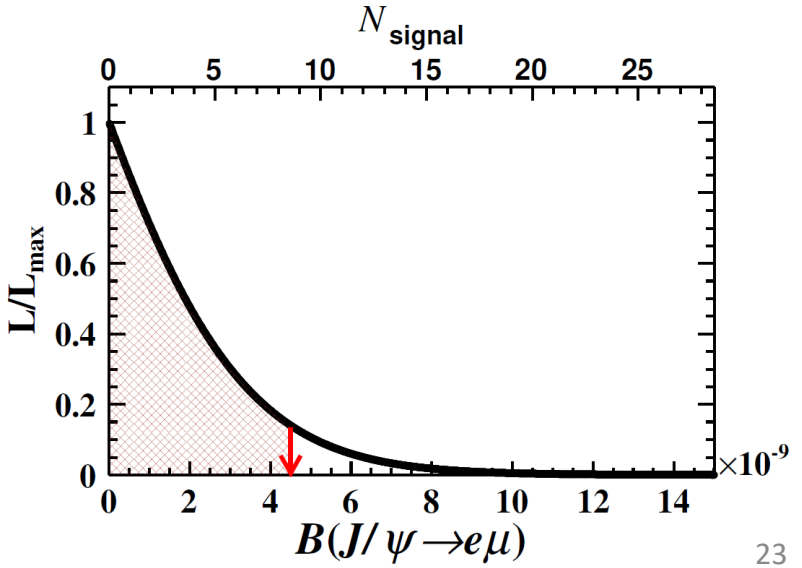
NEW

arXiv:2206.13956



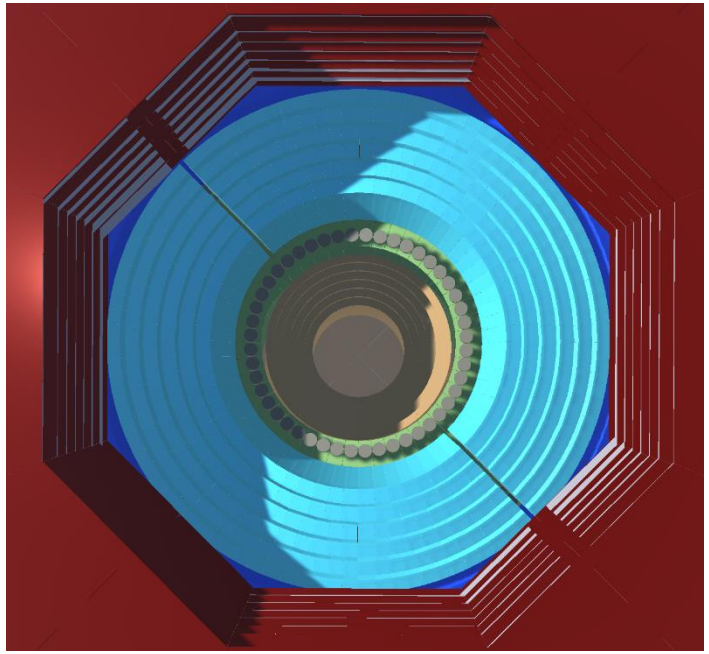






Summary

- The rare decays and violating decays (LNV, BNV, LFV) are essential to probe New Physics beyond the Standard Model
- BESIII has great potential with unique datasets and advanced analysis techniques
- BESIII has collected 10^{10} J/ψ and 3×10^{9} ψ' events
- BESIII will collect 20 fb^{-1} @ 3.773 GeV data sample
- More & better results are coming soon!



Thank you!