# Search for invisible decays and rare decays at BESIII

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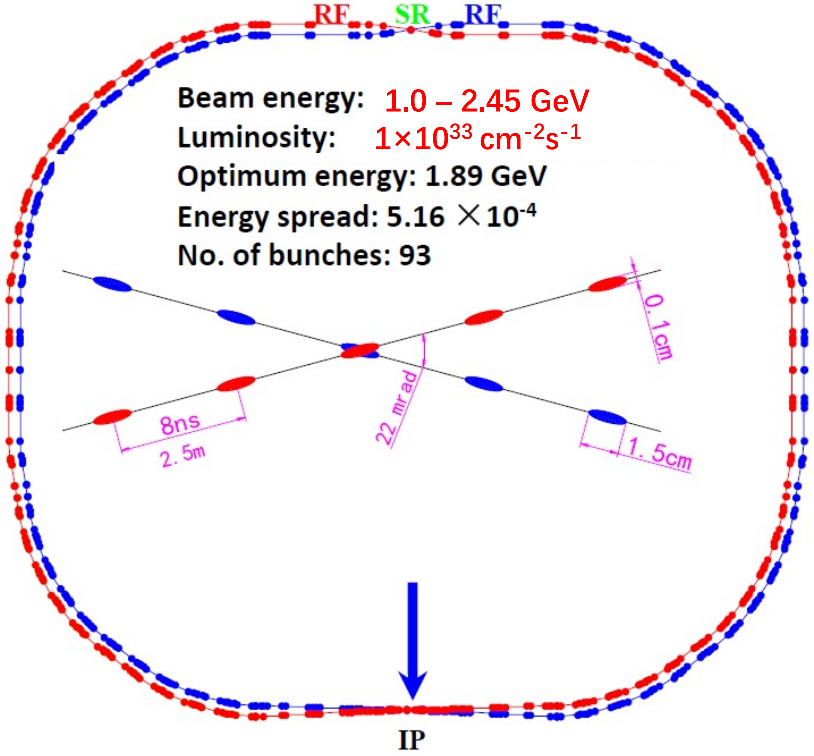
# Outline

- BEPCII and BESIII
- BESIII data samples
- Search for invisible decays
- Search for rare decays
- Search for LFV
- Summary

# BEPCII and BESIII

**Charm Factory**

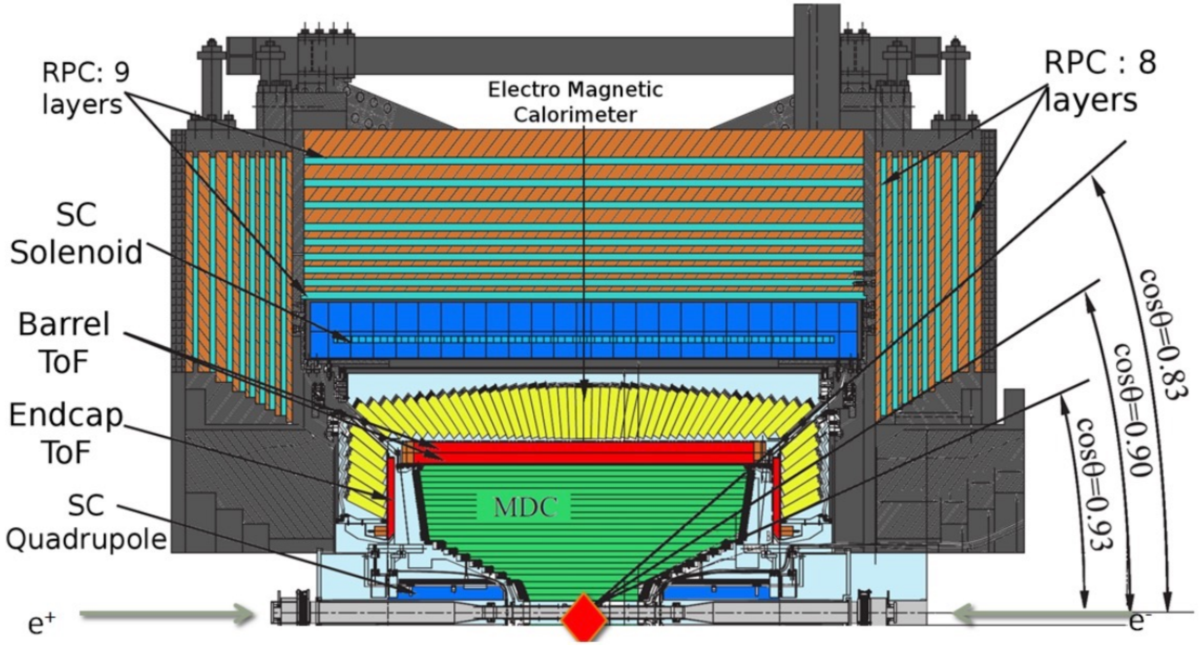
## Beijing Electron Positron Collider II




## BESIII Detector

MDC: σp=0.5% @ 1GeV/c
dE/dx: 6%

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

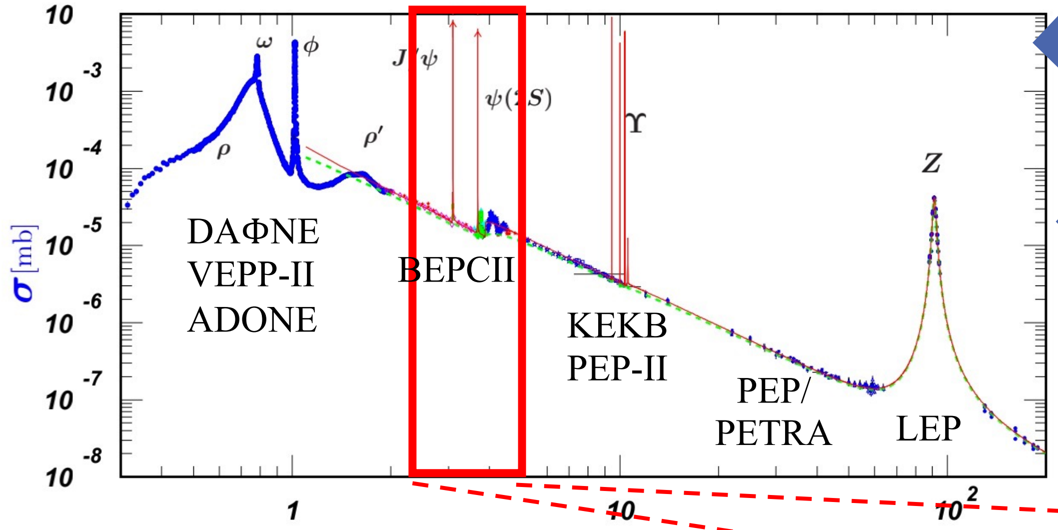


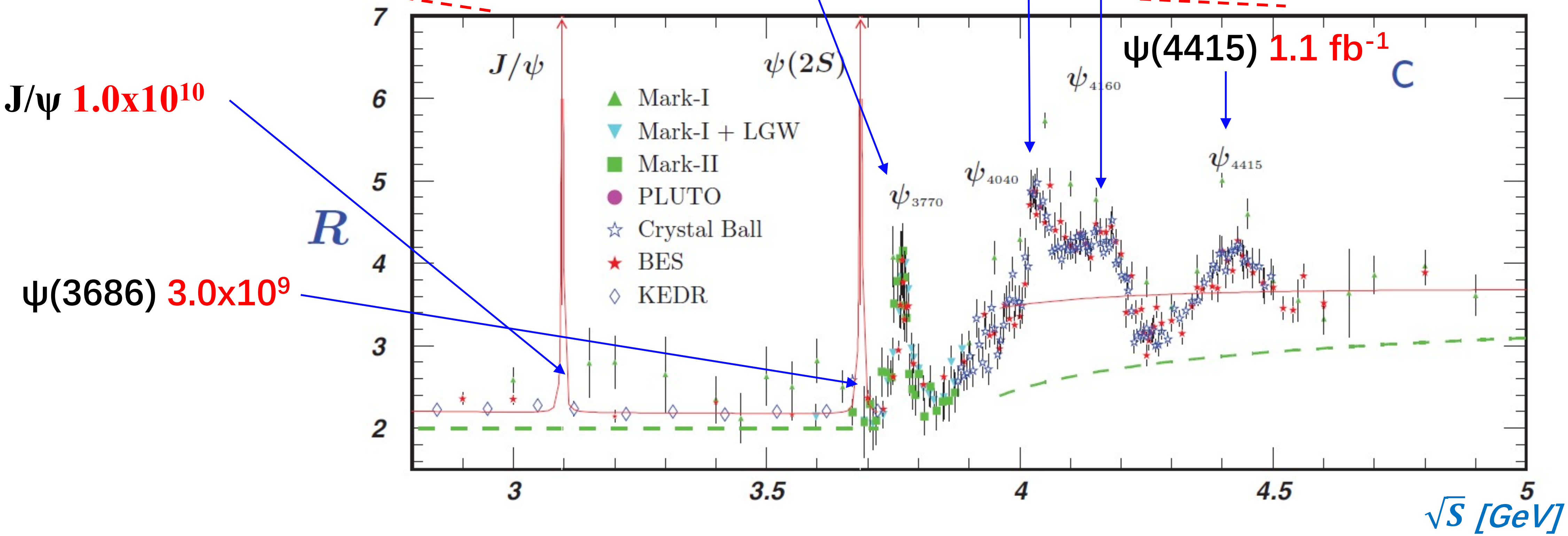

TOF: σT=68 (60) ps
barrel (endcap)

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

# BESIII data samples

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



# New Physics Searches at BESIII

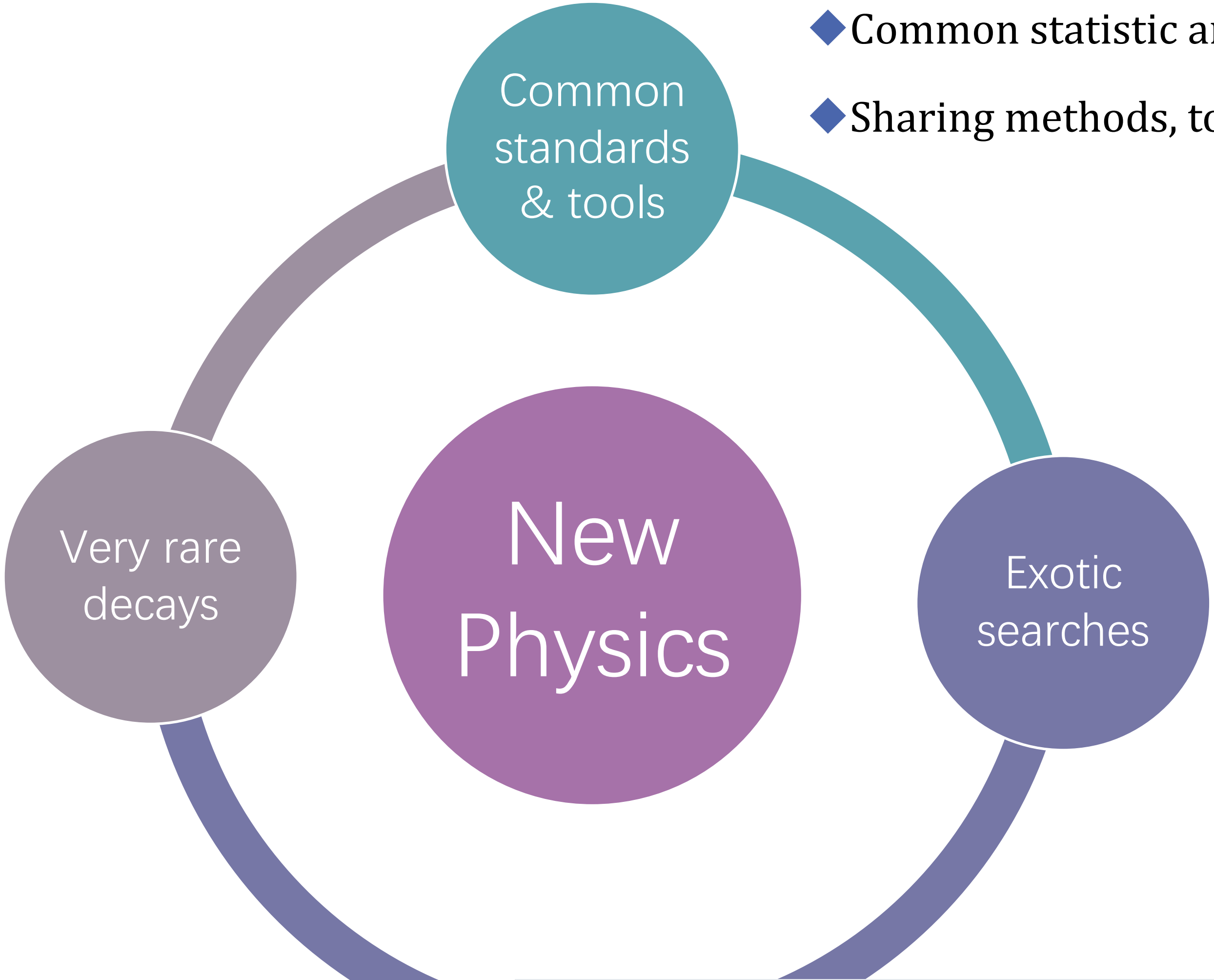
- Uniform blinding strategy and datasets
- Common statistic and standards
- Sharing methods, tools and codes

Symmetry

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

- FCNC processes
- Charmonium weak decays
- Other rare decays

Very rare



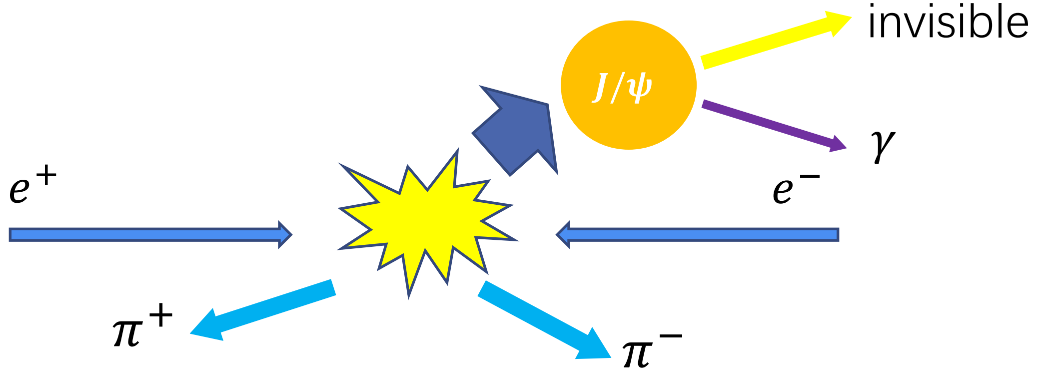

Exotic

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

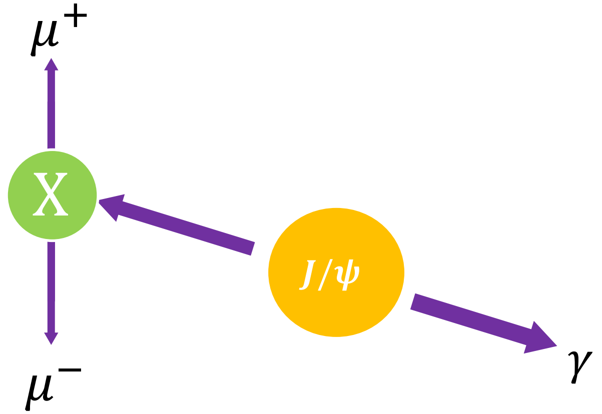
- New Physics Searches at the BESIII Experiment, S.J. Chen and S. Olsen, Nation Science Review 8, nwab189 (2021), arXiv: 2102.13290
- New Physics Program of BES, D.Y. Wang, in “30 Years of BES Physics”

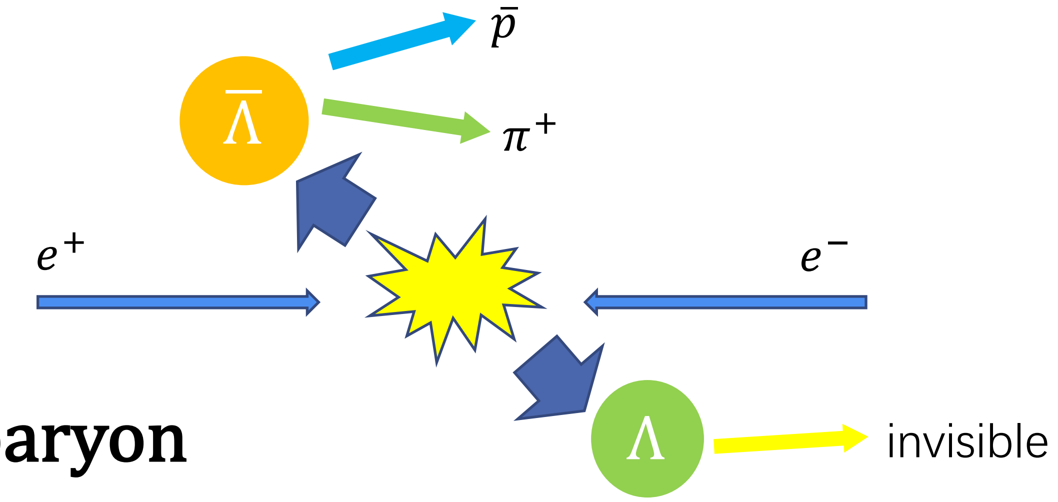
# Search for invisible decays at BESIII

- Search for $J/\psi \to \gamma$ + invisible via $\psi' \to \pi^+\pi^- J/\psi$




- Search for a CP -odd light Higgs boson in $J/\psi \to \gamma A^0$



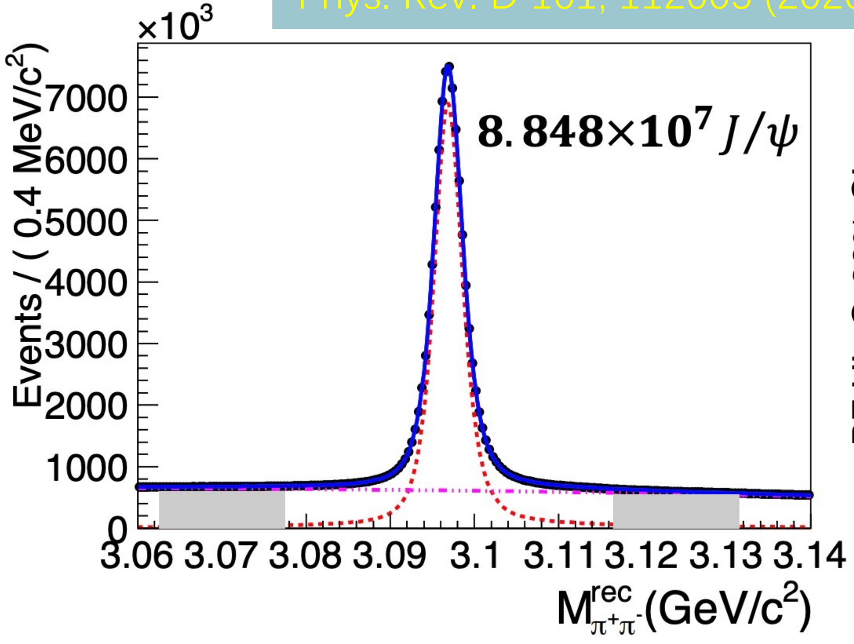

- Search for the invisible decay of $\Lambda$ baryon

# Search for J/ψ → γ + invisible via ψ'→ π⁺π⁻J/ψ

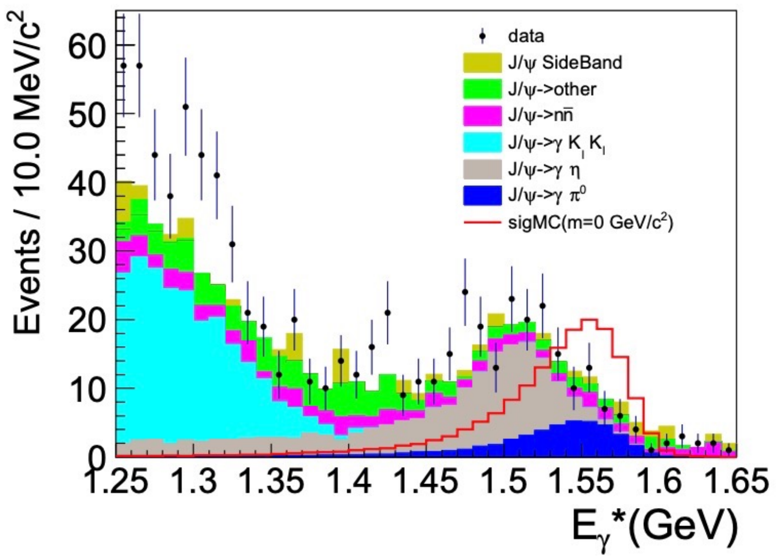
$$\frac{\mathcal{B}(V\to\gamma A^0)}{\mathcal{B}(V\to\mu^+\mu^-)}=\frac{G_F m_q^2 g_q^2 C_{\mathrm{QCD}}}{\sqrt{2}\pi\alpha}\left(1-\frac{m_{A^0}^2}{m_V^2}\right)$$

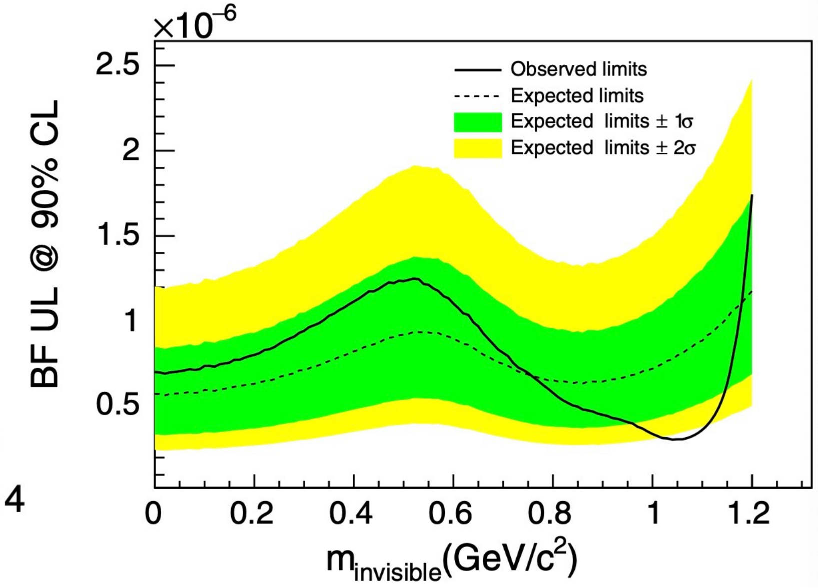
- A series of supersymmetric Standard Models, including Next-to-Minimal Supersymmetric Model, predict a CP-odd pseudoscalar Higgs ($A^0$). The $A^0$ can decay to two neutralinos.
- Using $(448.1 \pm 2.9)\times 10^6$ $\psi(3686)$ events produced via $\psi(3686)\to\pi^+\pi^- J/\psi$

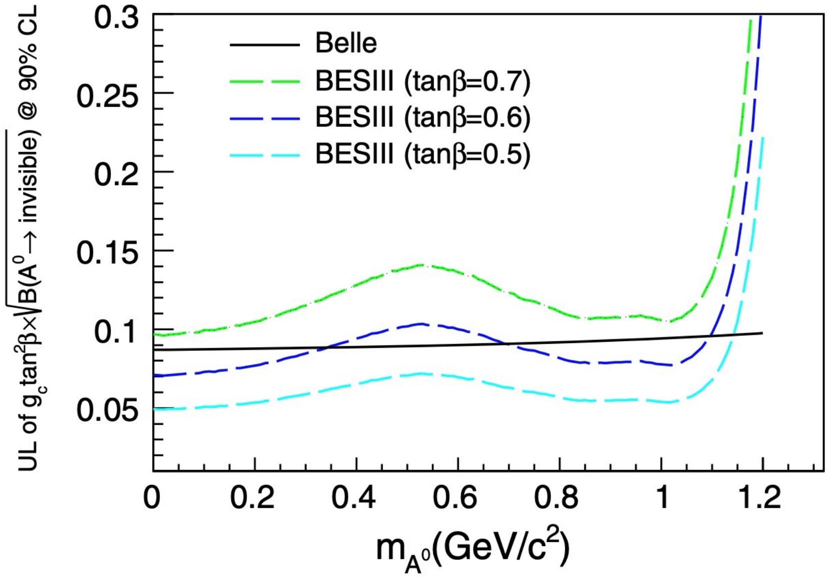
Phys. Rev. D 101, 112005 (2020)




- $\mathcal{B}(J/\psi \to \gamma\ invisible) < 7.0\times10^{-7}$ @ 90% C.L.
- ~6.2 better than CLEO-c's
- Calculate UL for $\beta$ and $\theta_A$
- $g_c = cos\theta_A/tan\beta$, $g_b = cos\theta_A tan\beta$
- Obtain better sensitivity with $tan\beta$< 0.6 compared to the Belle's result

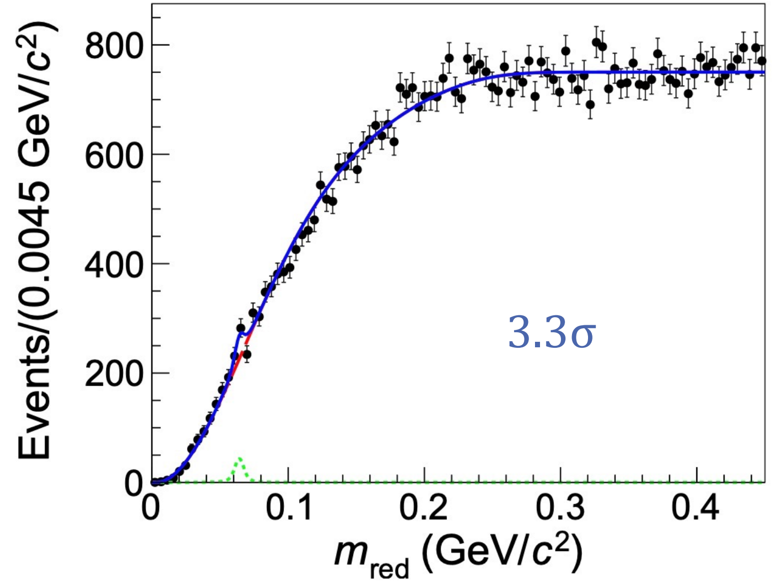


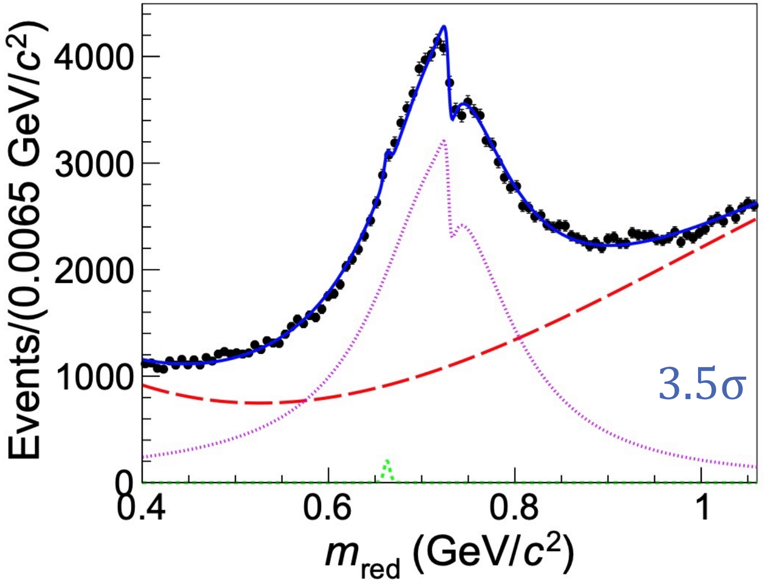



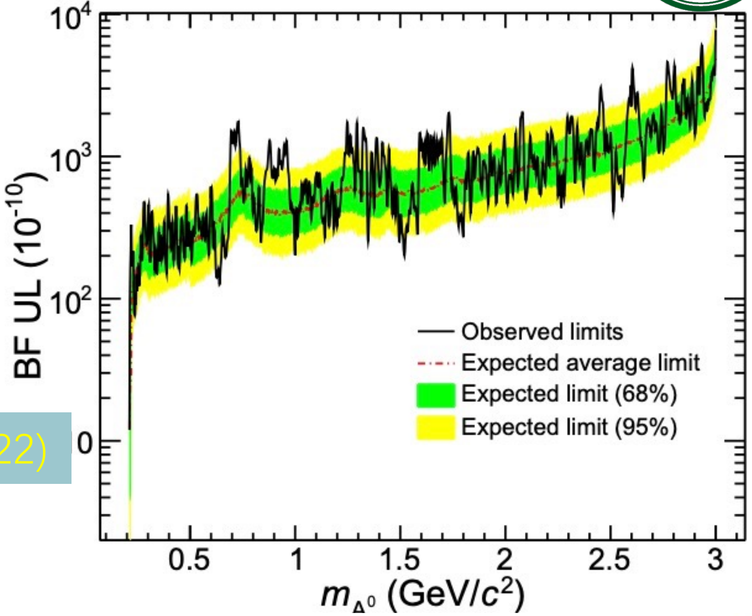
# Search for a CP-odd light Higgs boson in $J/\psi \to \gamma A^0$

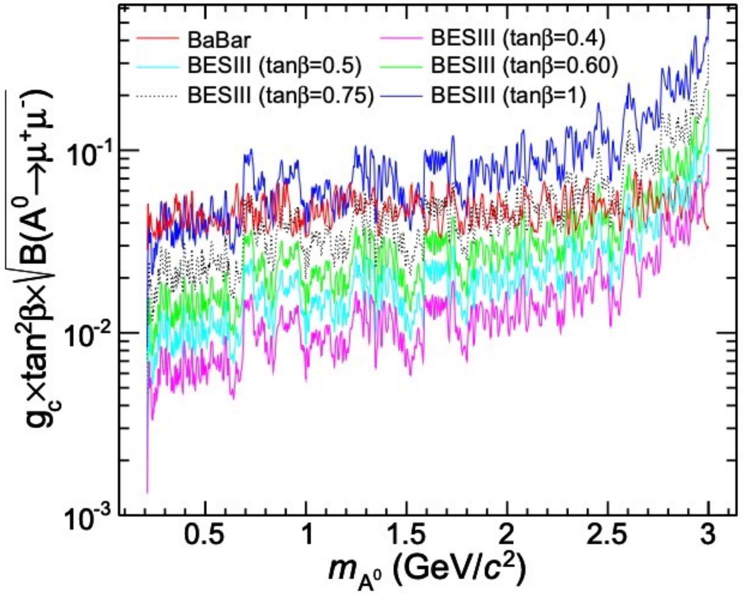
$$\frac{\mathcal{B}(V \to \gamma A^0)}{\mathcal{B}(V \to l^+ l^-)} = \frac{G_F m_q^2 g_q^2 C_{\mathrm{QCD}}}{\sqrt{2}\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_V^2}\right)$$



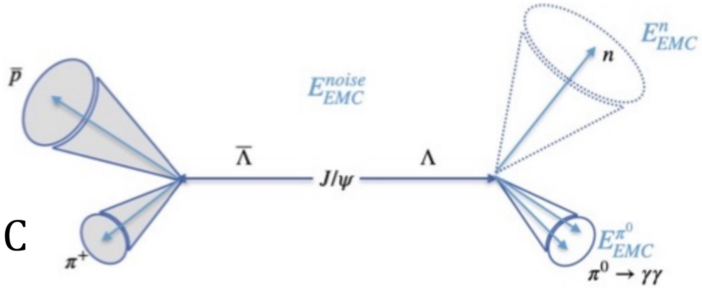




- The light particle X could be a Higgs-like boson $A^0$ , a spin-1 $U$ boson, or a pseudoscalar sgoldstino particle
- Search for di−muon decays of $A^0$ using 9 billion $J/\psi$ events Phys. Rev. D 105, 012008 (2022)
- Fits to the $m_{red} = \sqrt{m_{\mu^+\mu^-}^2 - 4m_\mu^2}$ distributions for (top) $m_{A^0} = 0.221\ \mathrm{GeV}/c^2$ and (bottom) $m_{A^0} = 0.696\ \mathrm{GeV}/c^2$
- $\mathcal{B}(J/\psi \to \gamma A^0)\times\mathcal{B}(A^0 \to \mu^+\mu^-)$ in range of $(1.2 - 778.0)\times10^{-9}$ @ 90% C.L. for $0.696 \le m_{A^0} \le 3.0\ \mathrm{GeV}/c^2$
- Better than BaBar for $m_{A^0} < 0.7\ \mathrm{GeV}/c^2$



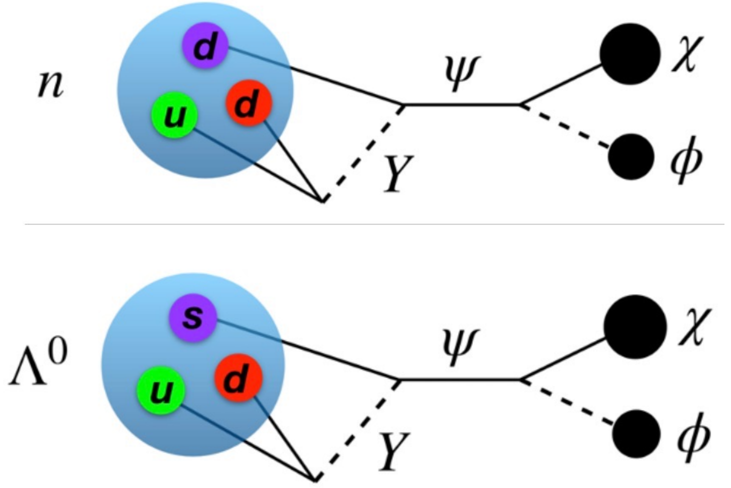



# Search for the invisible decay of Λ baryon




◆Dark matter may be represented by baryon matter with invisibles, and many theories suggest a potential correlation between baryon symmetry and dark sector

◆Neutron lifetime difference in beam method & storage methods → $\mathcal{B}(n \to p + X) \approx 99\%$



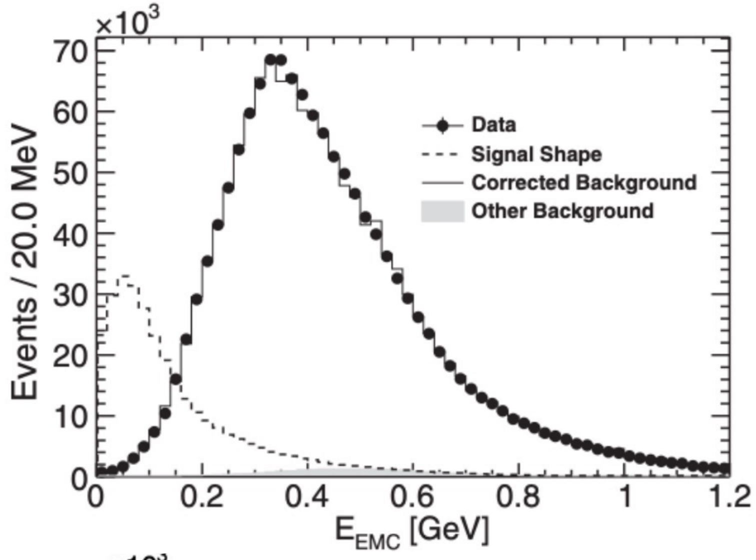

Phys. Rev. D 105, L071101 (2022)

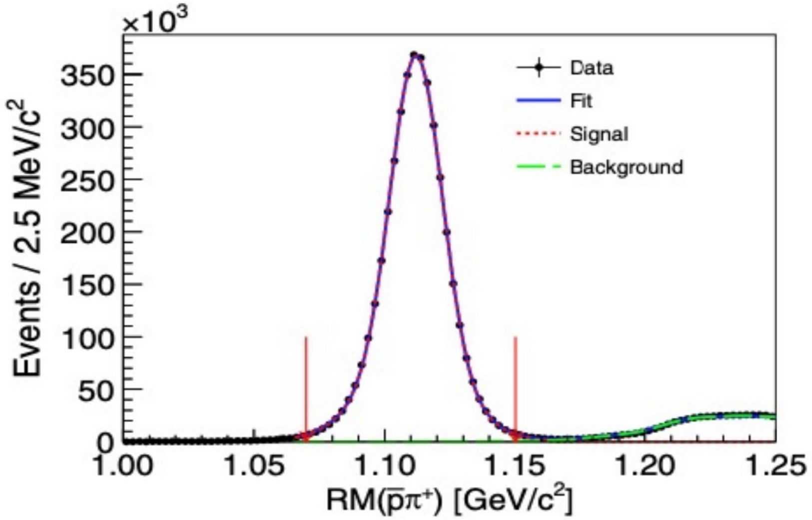
◆Search signal on total energy in EMC

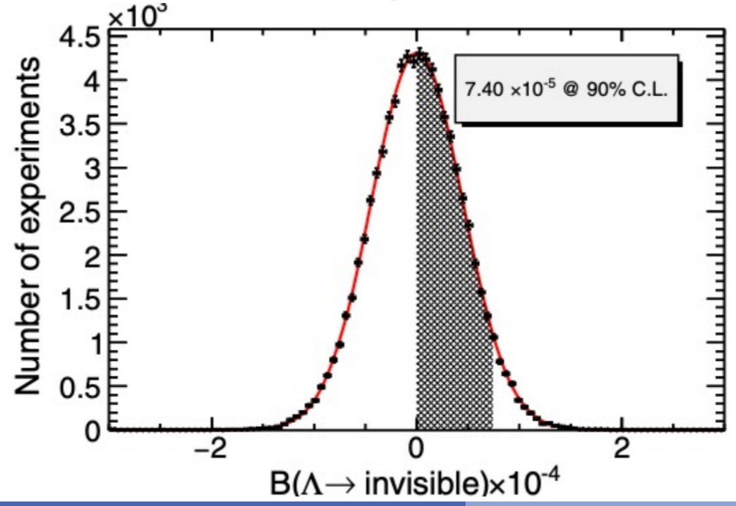
◆Main background: $\Lambda \to n\pi^0$

◆By control sample, get precise n's and noise's $E_{EMC}$ and correct MC simulation

◆$\mathcal{B}(\Lambda \to \ invisible) < 7.4\times10^{-5}$ @ 90% C.L. with 10B $J/\psi$ data

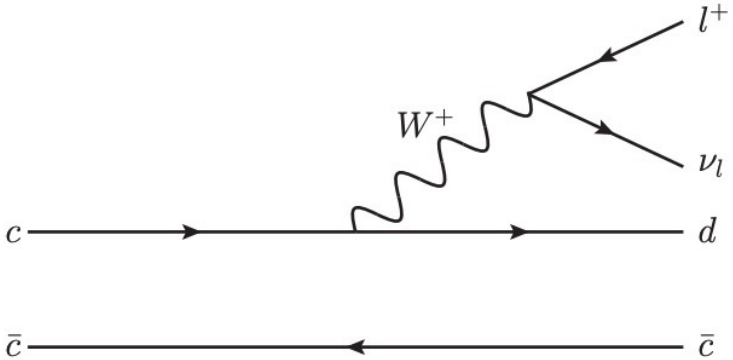


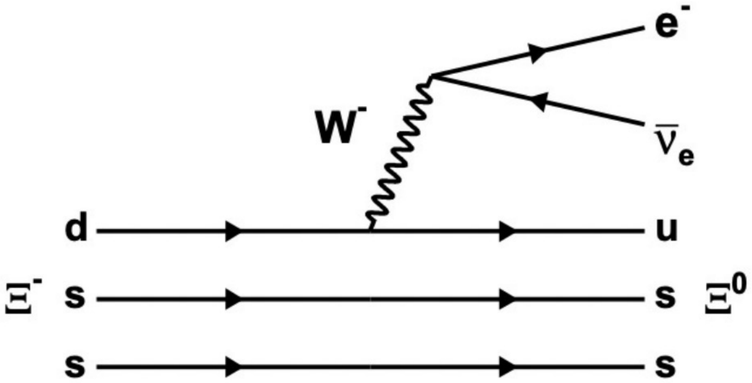



# Search for rare decays at BESIII

- Search for the charmonium weak decay $J/\psi \rightarrow D^{-}e^{+}\nu_{e}$

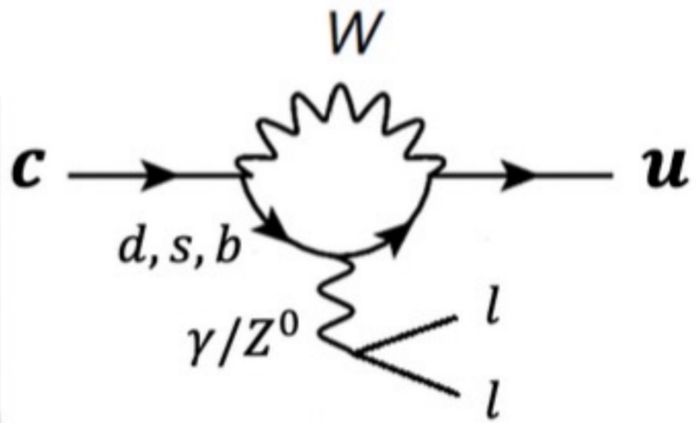



- Search for the hyperon semileptonic decay $\Xi^{-} \rightarrow \Xi^{0} e^{-} \bar{\nu}$




$\mu^{-}$

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



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

JHEP 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 Standard Model (SM)

◆$J/\psi \to D^- e^+ \nu,\ D^- \to K^+ \pi^- \pi^-$

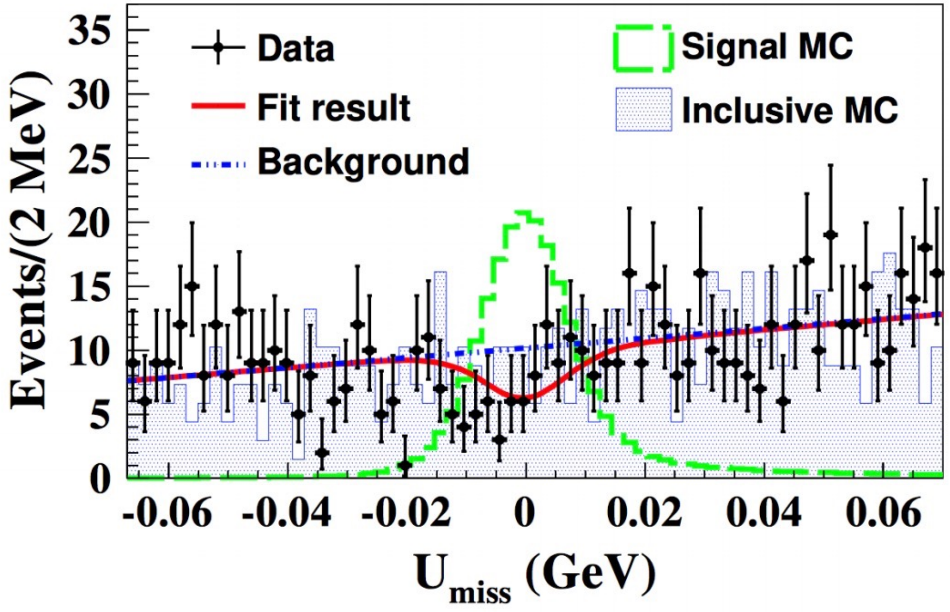
◆Use a fit on $U_{miss}$ to extract the signal.

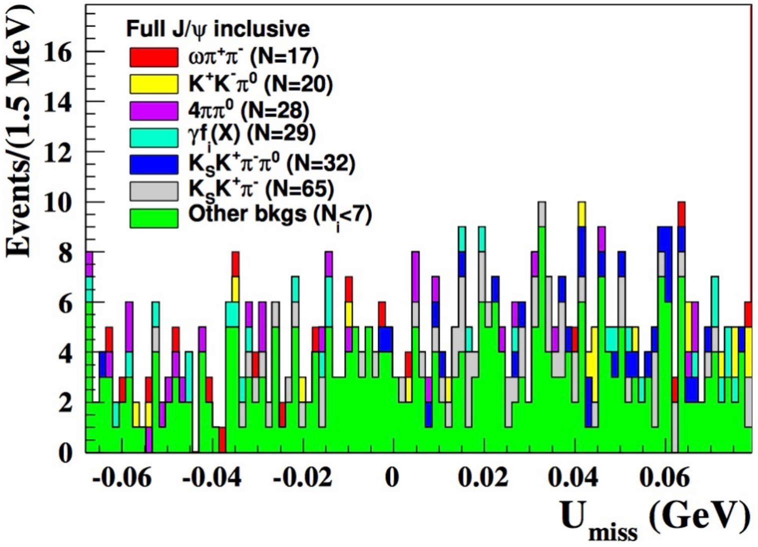
◆Two main backgrounds: (1) $\pi/K$ misidentified as $e$

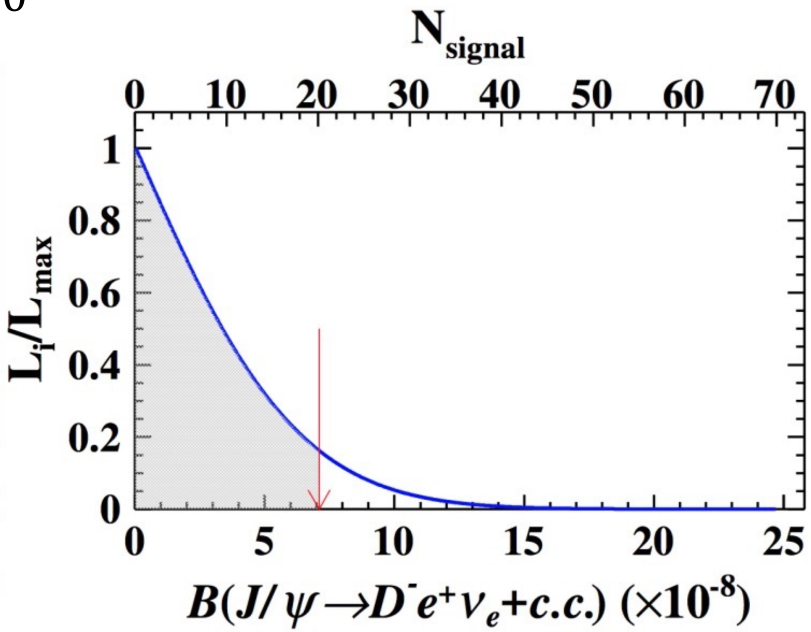
(2) Gamma conversion with $e$ misidentified as $\pi/K$

◆$\mathcal{B}(J/\psi \to D^- e^+ \nu + c.c.) < 7.1\times10^{-8}$ @ 90% C.L.

◆Compatible with the SM theoretical predictions, and puts a stringent constraint on the parameter spaces for different new physics models predicting BFs at the order of $10^{-5}$



◆Hyperon semi-leptonic decays provide important information on the interplay between weak interactions and hadronic structures formed through strong interactions

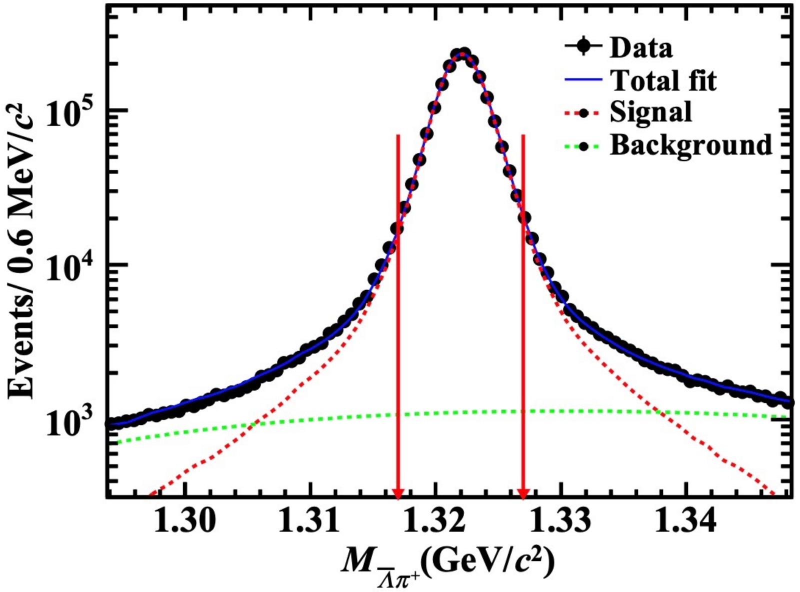
◆Using $(10.087 \pm 0.044)\times 10^9$ $J/\psi$ events

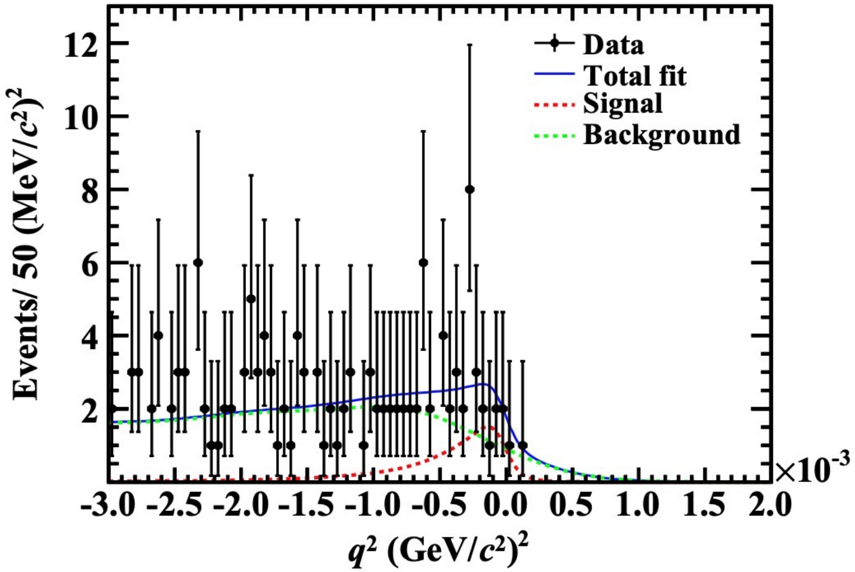
◆$\mathrm{M}^{\mathrm{recoil}}_{\bar{\Lambda}\pi^+} = \sqrt{(E_{\mathrm{CM}} - E_{\bar{\Lambda}\pi^+})^2 - |\vec{p}_{\bar{\Lambda}\pi^+}|^2}$

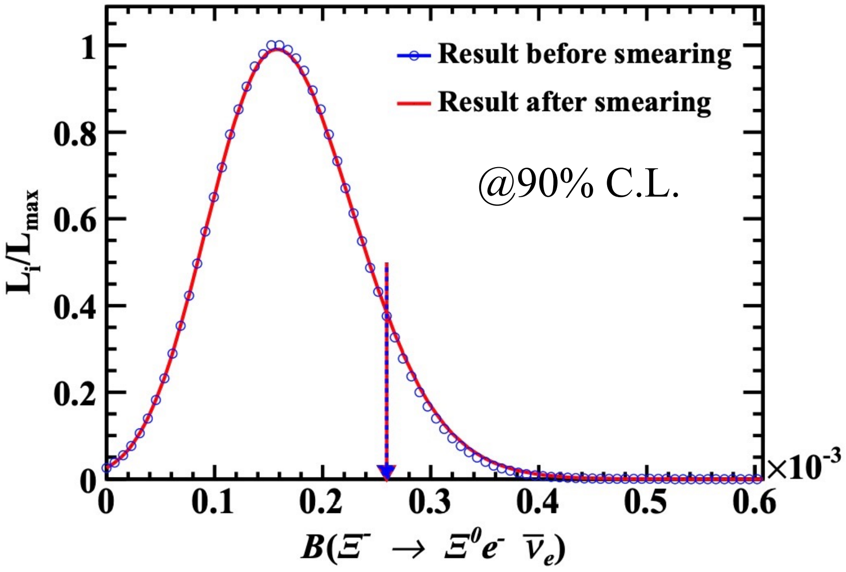
◆To extract the DT yield, the invariant mass squared of the lepton-neutrino system, $q^2 = (E_{\mathrm{CM}} - E_{\bar{\Xi}^+} - E_{\Xi^0})^2 - (\vec{p}_{\mathrm{CM}} - \vec{p}_{\bar{\Xi}^+} - \vec{p}_{\Xi^0})^2$

◆$\mathcal{B}(\Xi^- \to \Xi^0 e^- \overline{\nu_e}) < 2.59\times 10^{-4}$ @ 90% C.L.

Phys. Rev. D 104, 072007 (2021)



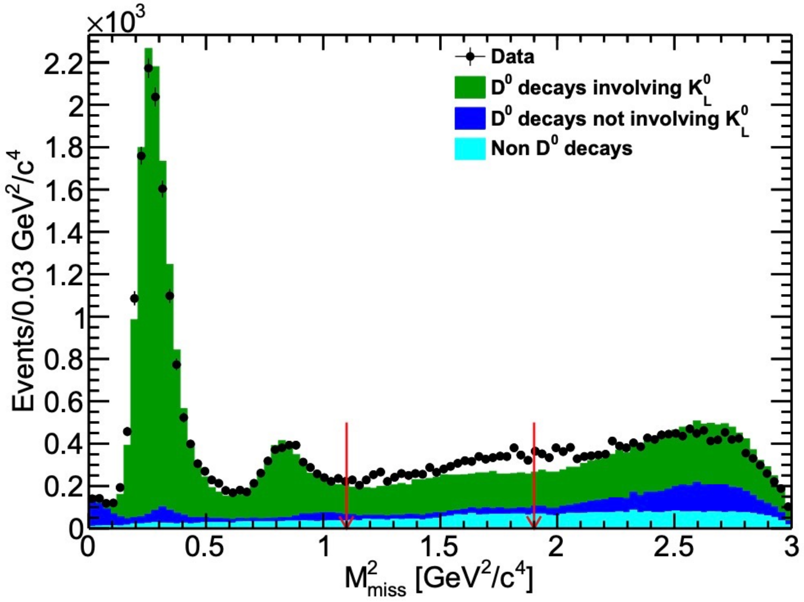



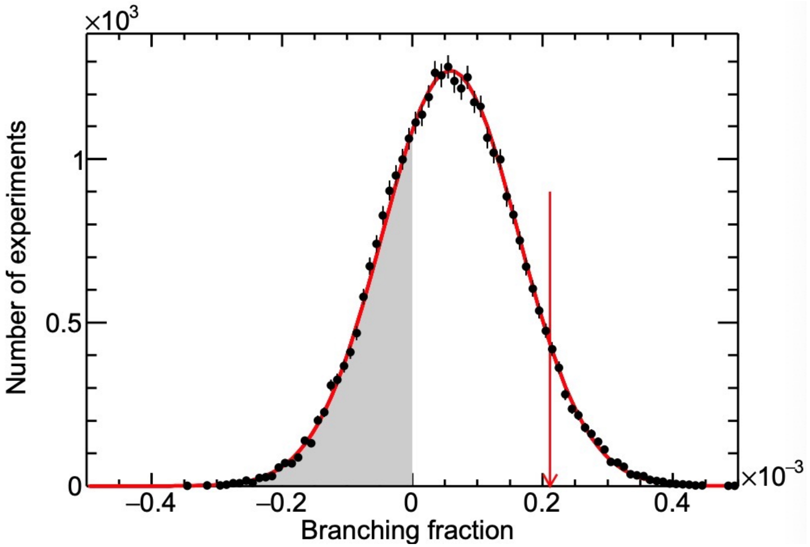
# Search for the FCNC process $D^0 \to \pi^0 \nu\bar{\nu}$

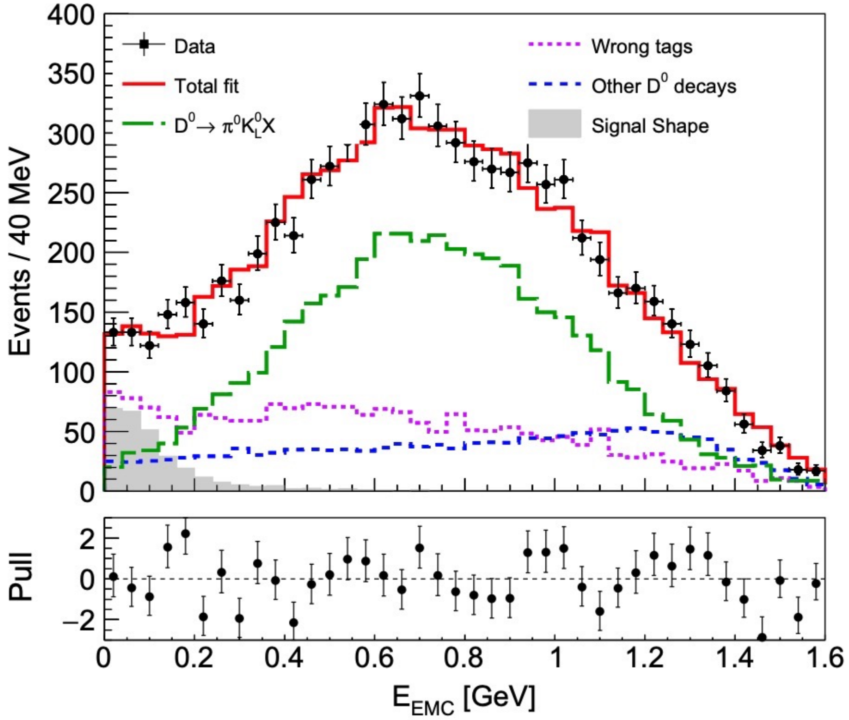
- In SM, FCNC is strongly suppressed by GIM mechanism and can happen only through loop diagram, leading to a very small BF $\sim 10^{-9}$, theoretically
- The suppression in charm decays is much stronger than those in B and K system due to stronger diagram cancellation than the down-type quarks

- Discriminator: EMC energy not associated with signal and tag decays
- $M^2_{\mathrm{miss}} = (E_D)^2/c^4 - |\vec{p}_{\pi^0}|^2/c^4$
- $\mathcal{B}(D^0 \to \pi^0 \nu\bar{\nu}) < 2.1\times10^{-4}$ @ 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 CLFV decay $J/\psi \to e\tau$
- Search for CLFV decay $J/\psi \to e\mu$

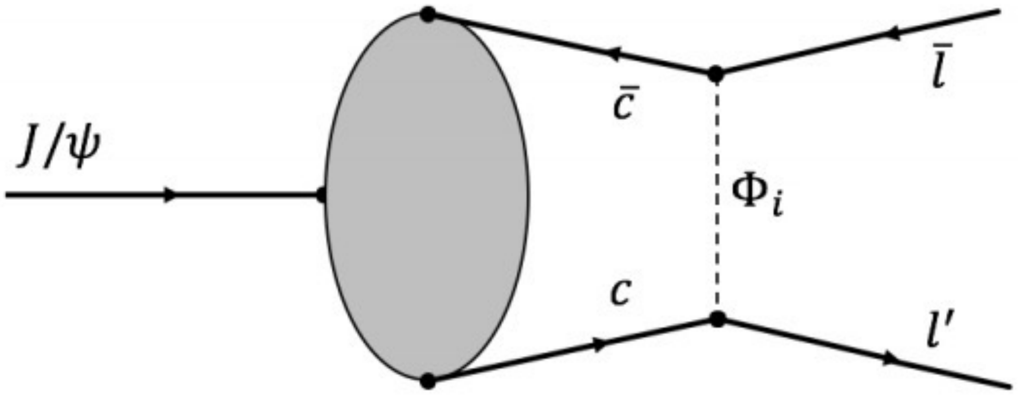



Diagram via leptoquarks

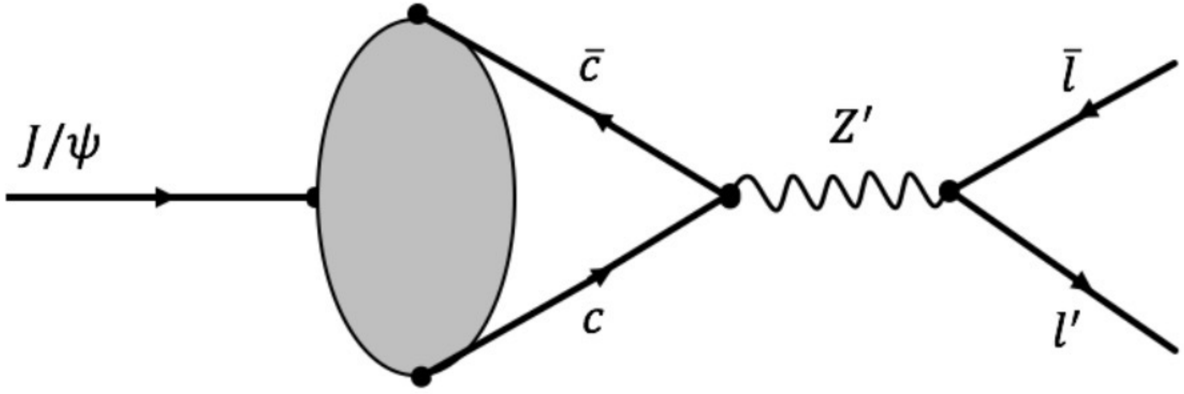



Diagram via a Z’ in TC2 models

Phys. Lett. B 496, 89 (2000)

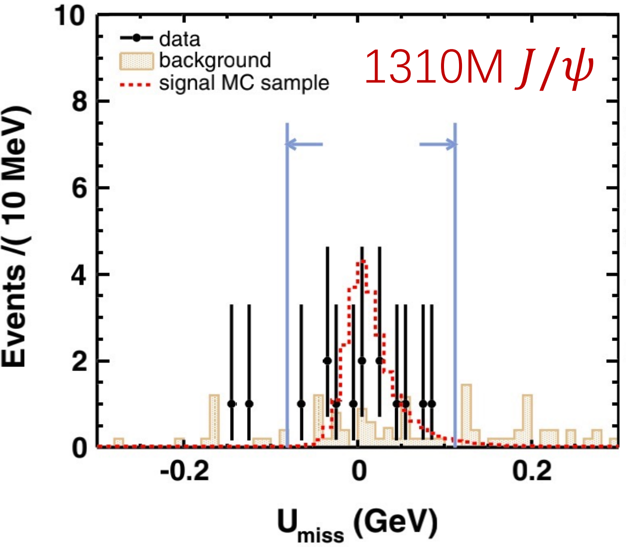
# Search for charged lepton flavor violating decay

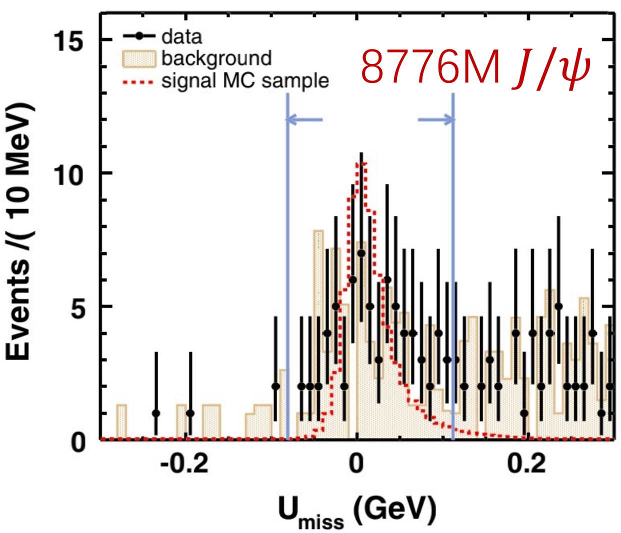
- New physics models predicting $\mathcal{B}(J/\psi \to e\mu)$ to $10^{-16} \sim 10^{-9}$, $\mathcal{B}(J/\psi \to e\tau)$ to $10^{-10} \sim 10^{-8}$

## $J/\psi \to e\tau$

- $J/\psi \to e\tau, \tau \to \pi\pi^0\nu, U_{miss} = E_{miss} - c|\vec{P}_{miss}|$
- $\mathcal{B}(J/\psi \to e\tau)$<7.5×$10^{-8}$ @ 90% C.L.
- The 1st submitted paper based on full 10 billion $J/\psi$ data of BESIII

Phys. Rev. D 103, 112007 (2021)

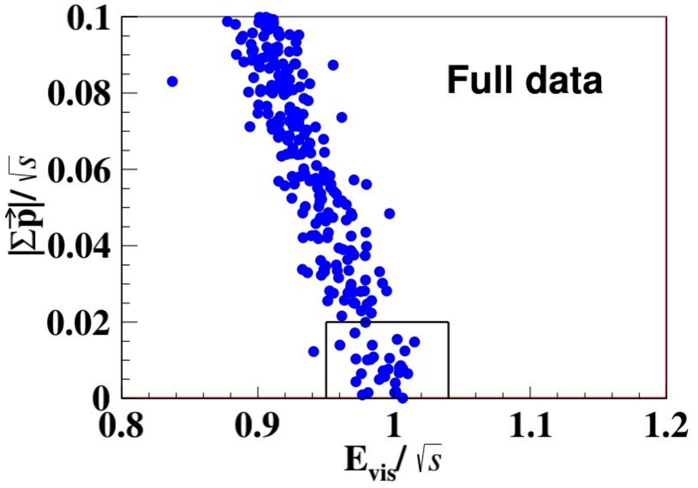


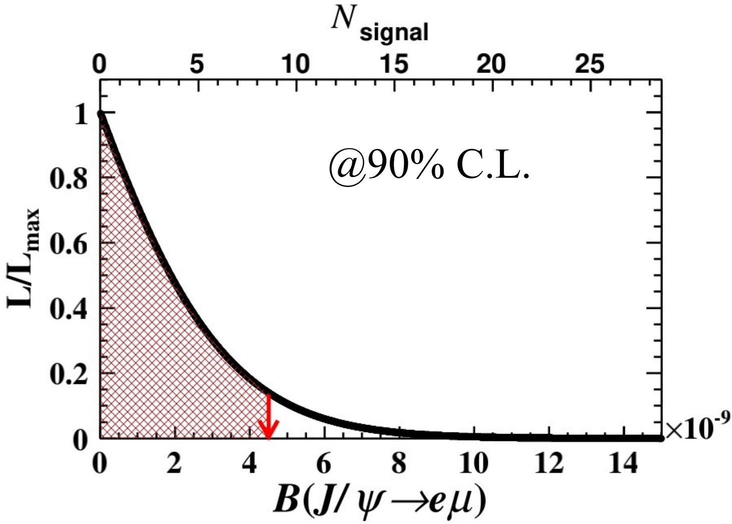




## $J/\psi \to e\mu$

arXiv: 2206.13956

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



# Summary

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

# Thank you