Dark Sector and Rare Decay Searches at BESIII

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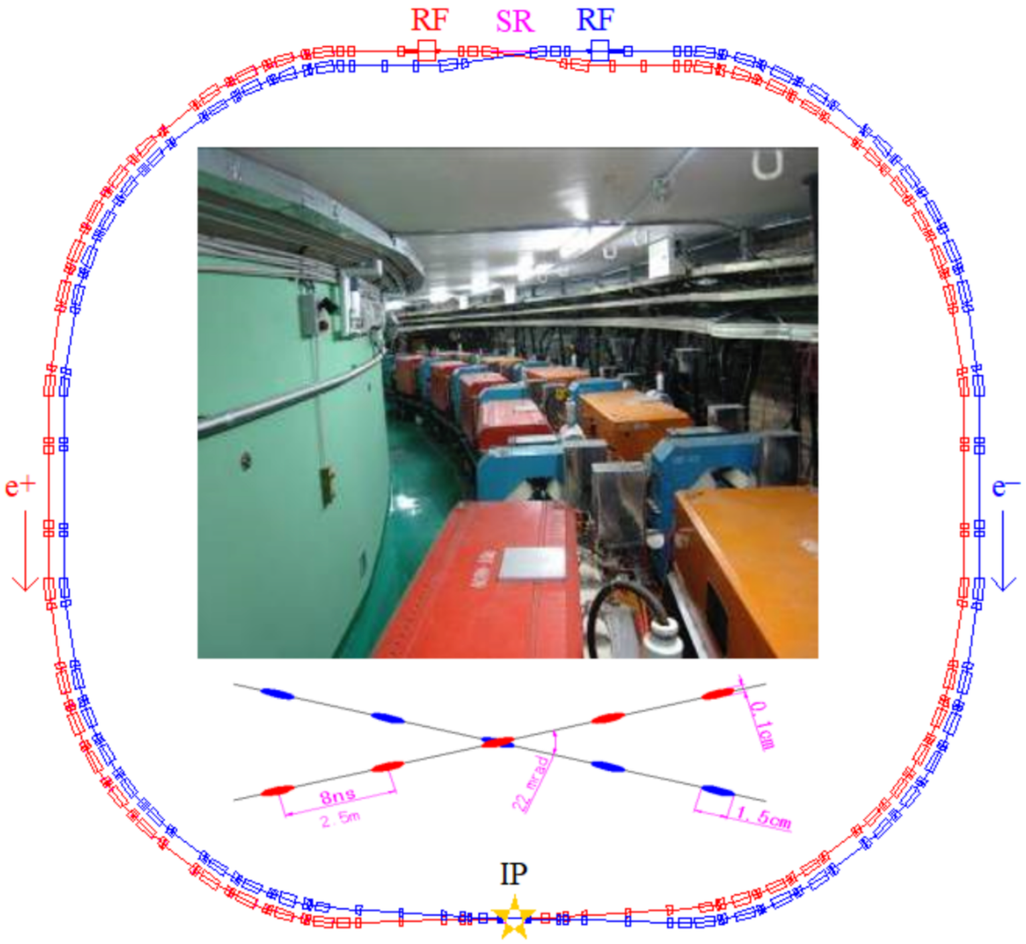
Electroweak session of the 59th Rencontres de Moriond
March 23, 2025, La Thuile

Outline

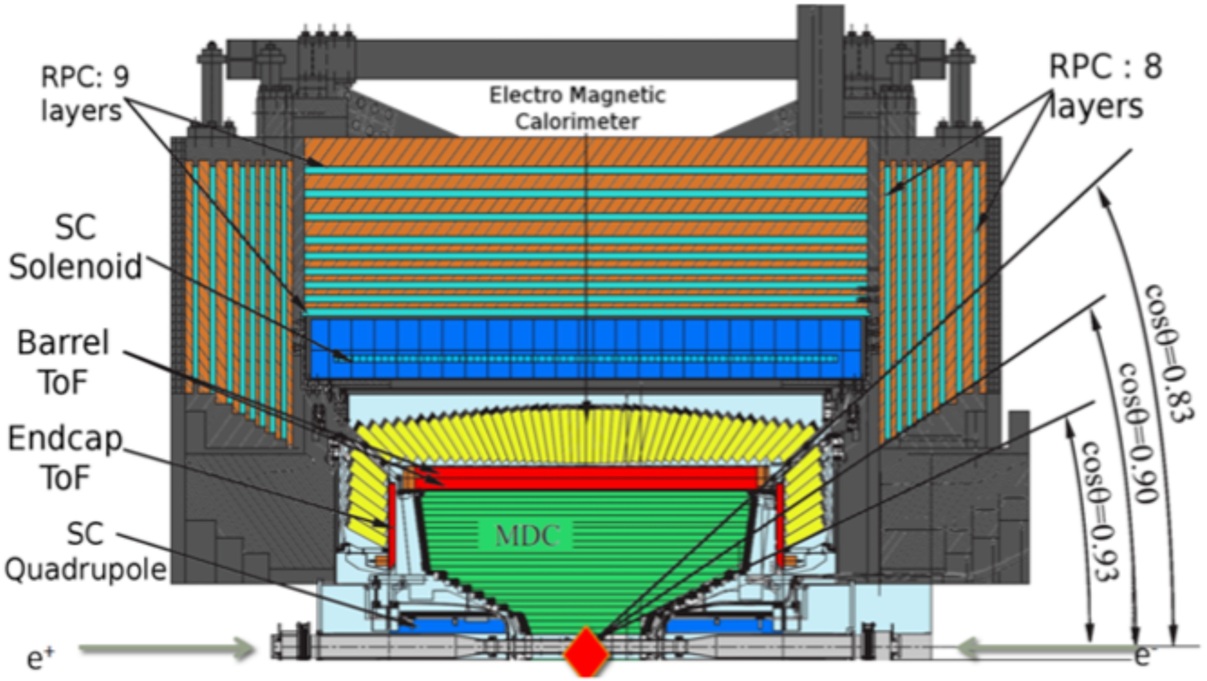
- BEPCII & BESIII
- New physics search at BESIII
- Very rare decays
  - Charmonium weak decays
  - FCNC processes
- Symmetry breaking decays
  - Baryon/Lepton Number Violation
- Summary

BEPCII and BESIII

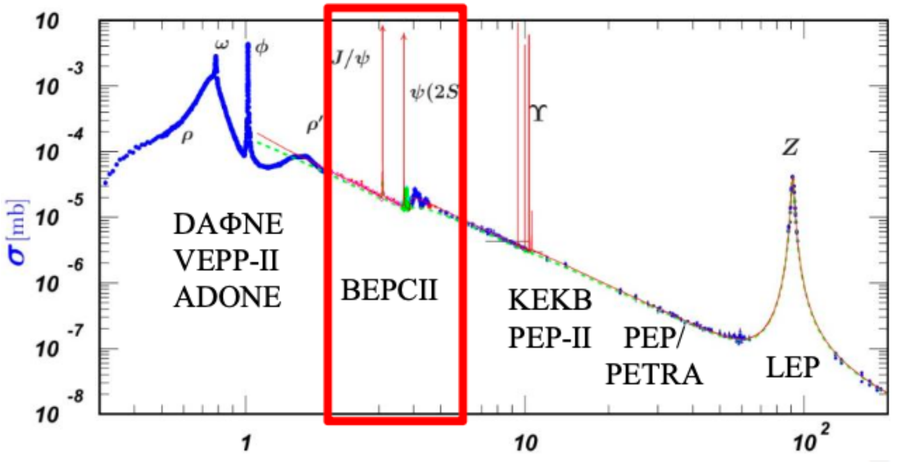
Beijing Electron Positron Collider II (BEPCII) is a double-ring collider, designed for high-energy physics research in the tau-charm energy region.



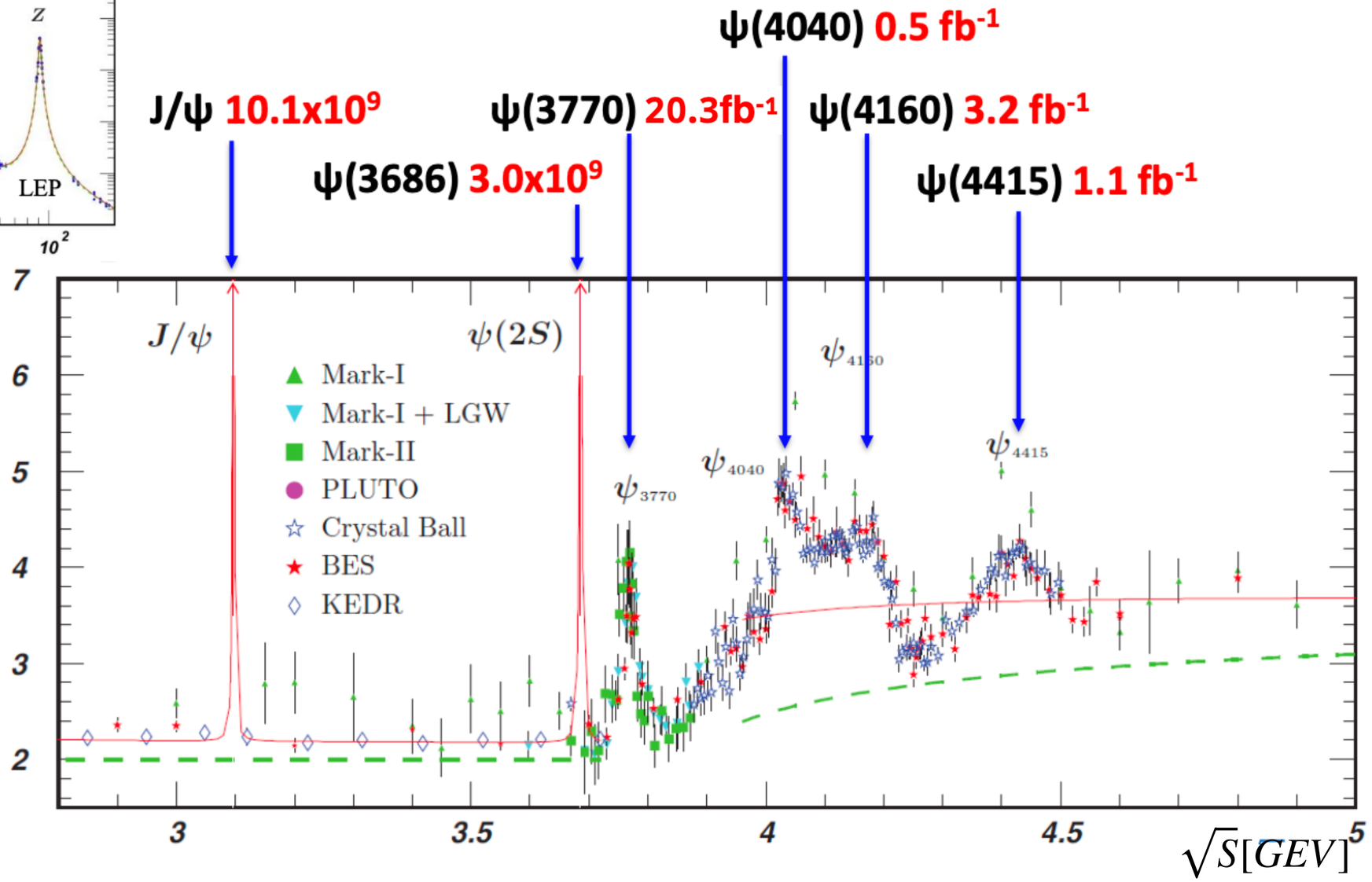
BESIII detector is a key part of the BEPCII collider. It can detect particles



Charmonium Data at BESIII



- The energy regions and the number of events collected by BESIII
- BESIII has collected the largest J/ψ & $\psi(3686)$ data samples on threshold
- $> 20\, fb^{-1}$ of data above 4.0 GeV in total



New Physics Searches at BESIII

In BESIII, we're not just studying known physics—we're also looking for signs of new physics beyond the Standard Model.

- Common standards & tools
  - Uniform blinding strategy and datasets
  - Common statistic and standards
  - Sharing methods, tools and codes
- Exotic searches
  - Dark photon
  - Invisible particles
  - Light Higgs, Z’ boson
  - Exotic resonances

- Symmetry
  - BNV & LNV processes
  - LFV processes
  - Other symmetry violation
- Very rare decay
  - FCNC processes
  - Charmonium weak decays
  - Other rare decays

Search for the rare decay $J/\psi \to \gamma D_0$ at BESIII

- First search for the rare decay $J/\psi \to \gamma D_0$ using $(10087 \pm 44) \times 10^6$ J/ψ events collected with the BESIII detector.
- Results are consistent with a background-only hypothesis.
- The upper limit on the branching fraction of $B(J/\psi \to \gamma D_0 + c\,.\,c.)$ is $< 9.1 \times 10^{-8}$ at 90% C.L., the most stringent limit to date.
- Although the measurement doesn't reach SM prediction precision, it provides a valuable reference for NP model studies and constrains parameter phase space.
- Sensitivity could be enhanced with a larger J/ψ sample, potentially achievable in future experiments.

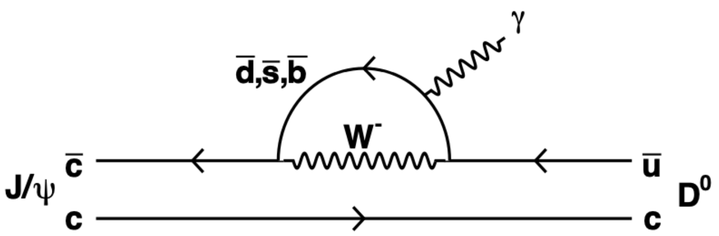


Fig1: Feynman diagram for $J/\psi \to \gamma D_0$

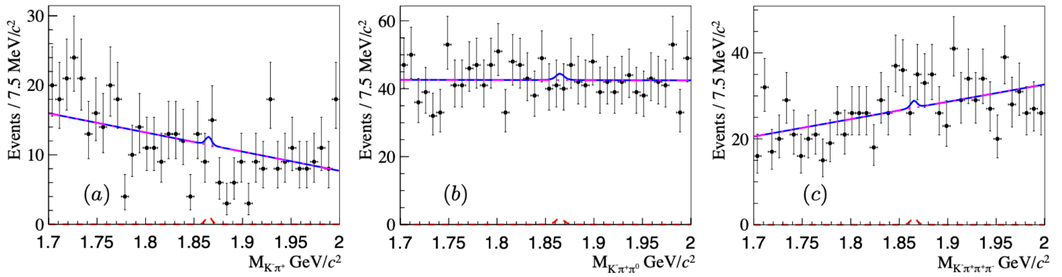


Fig2: The simultaneous fit results

Search for the rare decays $D_s^+ \to h^+(h0)e^+e^-$

- Used 7.33 fb^{-1} of e^+e^- collision data $\sqrt{s} = 4.128 - 4.226$ GeV from BESIII to search for rare decays $D_s^+ \to h^+(h0)e^+e^-$.
- $D_s^+ \to \pi^+\phi, \phi \to e^+e^-$ is observed with a statistical significance of 7.8σ
- The evidence of $D_s^+ \to \rho^+\phi, \phi \to e^+e^-$, is found for the first time with 4.4σ significance.
- Branching Fraction:
  - $B(D_s^+ \to \pi^+\phi, \phi \to e^+e^-) = 1.17 \times 10^{-5}$
  - $B(D_s^+ \to \rho^+\phi, \phi \to e^+e^-) = 2.44 \times 10^{-5}$
- No significant signal of the four-body rare decays ($D_s^+ \to \pi^+\pi^0e^+e^-$, $D_s^+ \to K^+\pi^0e^+e^-$, $D_s^+ \to \pi^+K_s^0e^+e^-$) is observed
- The upper limits on the BFs of these decays are set to be in $(7.0 - 8.1) \times 10^{-5}$ at the 90% confidence level

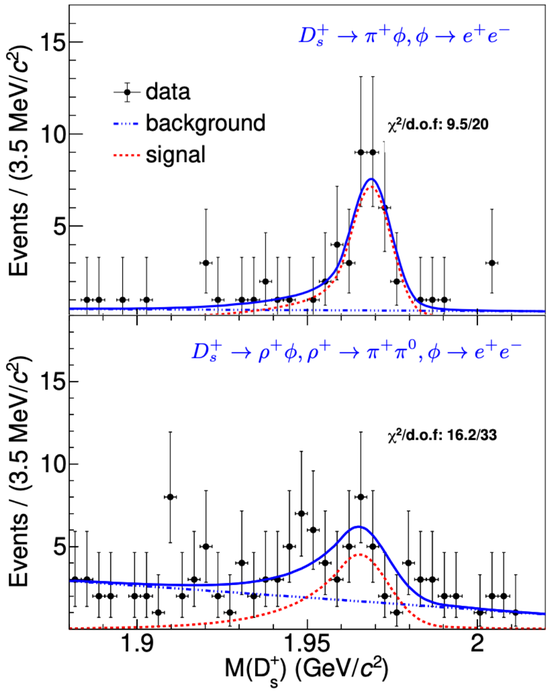


Fig1: The data distributions and fit results for two resonant decay modes

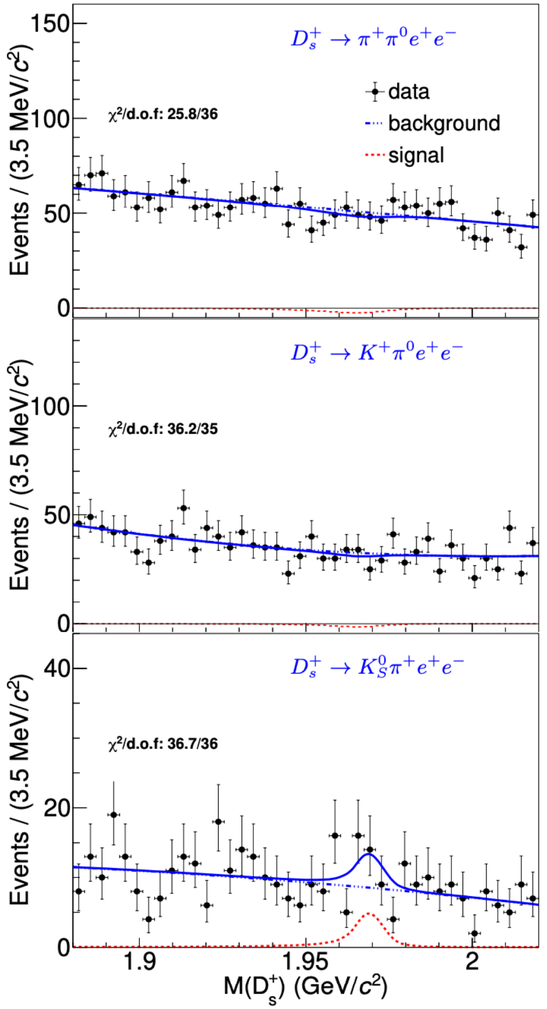


Fig2: The data distributions and fit results for the three four- body decay modes

Search for the FCNC charmonium decay $J/\psi \to D^0\mu^+\mu^- + \text{c.c.}$

- The FCNC decay $J/\psi \to D^0\mu^+\mu^- + \text{c.c.}$ is searched for the first time based on $(10087 \pm 44) \times 10^6$ J/ψ events collected by the BESIII detector.
- Results:
  - No significant signal is observed.
  - Upper limit on the branching fraction < 1.1×10^{-7} (at 90% confidence level)
- This is the first search for a charmonium FCNC process involving muons in the final state, and the result is compatible with the SM prediction

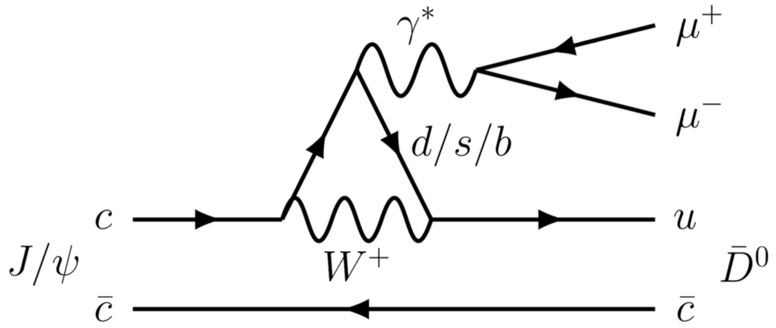


Fig1: Feynman diagram for the $J/\psi \to D^0\mu^+\mu^- + \text{c.c.}$ decay in the SM

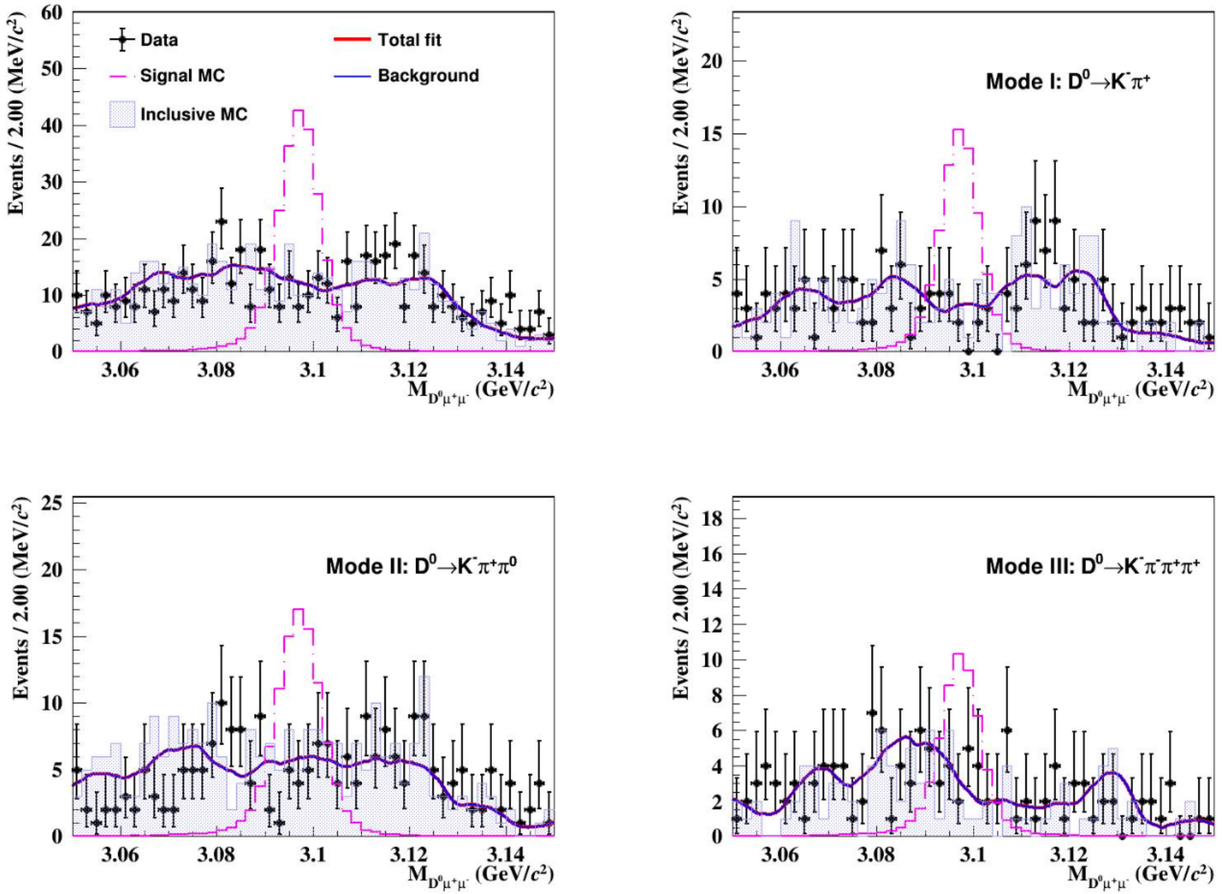


Fig2: The distribution of the simultaneous fit

Search for the massless dark photon with $D^0 \to \omega\gamma'$ and $D^0 \to \gamma\gamma'$

- Search for the massless dark photon and place constraints on the new physics scale in the charm FCNC processes $D^0 \to \omega\gamma'$ and $D^0 \to \gamma\gamma'$ for the first time.
- Used 7.9 fb^{-1} of e^+e^- collision data at$\sqrt{s} = 3.773$ GeV from BESIII
- No significant signals are observed, and No evidence of massless dark photon decays observed.
- Upper Limits on Branching Fractions (90% confidence level):
  - $B(D^0 \to \omega\gamma') < 1.1 \times 10^{-5}$
  - $B(D^0 \to \gamma\gamma') < 2.0 \times 10^{-6}$
- The most stringent limit on the new physics energy scale associated setting $|C|^2 + |C_5|^2 < 8.2 \times 10^{-17}$ GeV^{-2} at 90% C.L.

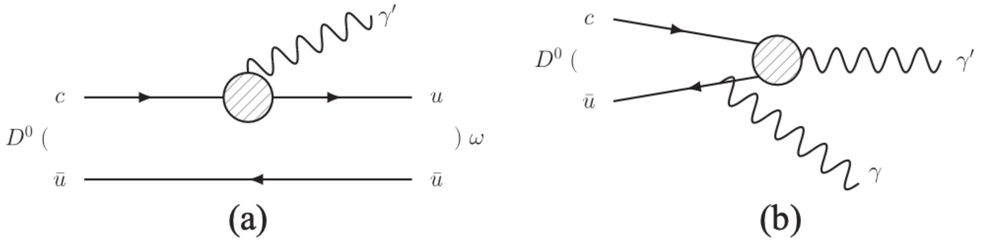


FIG. 1. The Feynman diagrams of $D^0 \to \omega\gamma'$ (a) and $D^0 \to \gamma\gamma'$

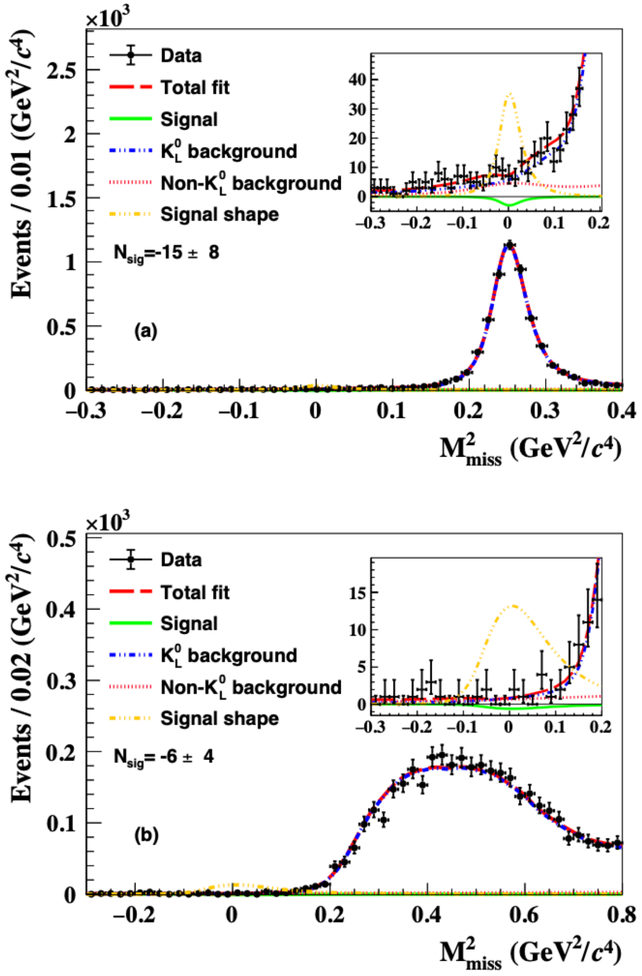


FIG 2. The fit results

Search for K_S^0 invisible decays

- Based on $(10087 \pm 44) \times 10^6$ J/ψ events collected with the BESIII detector, we search for K_S^0 invisible decays via the $J/\psi \to \phi K_S^0 K_S^0$ for the first time.
- Results:
  - No significant signal observed.
  - Upper limit on the branching fraction set at 8.4×10^{-4} (at 90% confidence level)
- This work provides the first direct measurement of the BF of $K_S^0 \to$ invisible, with results that are compatible with the indirect estimation.

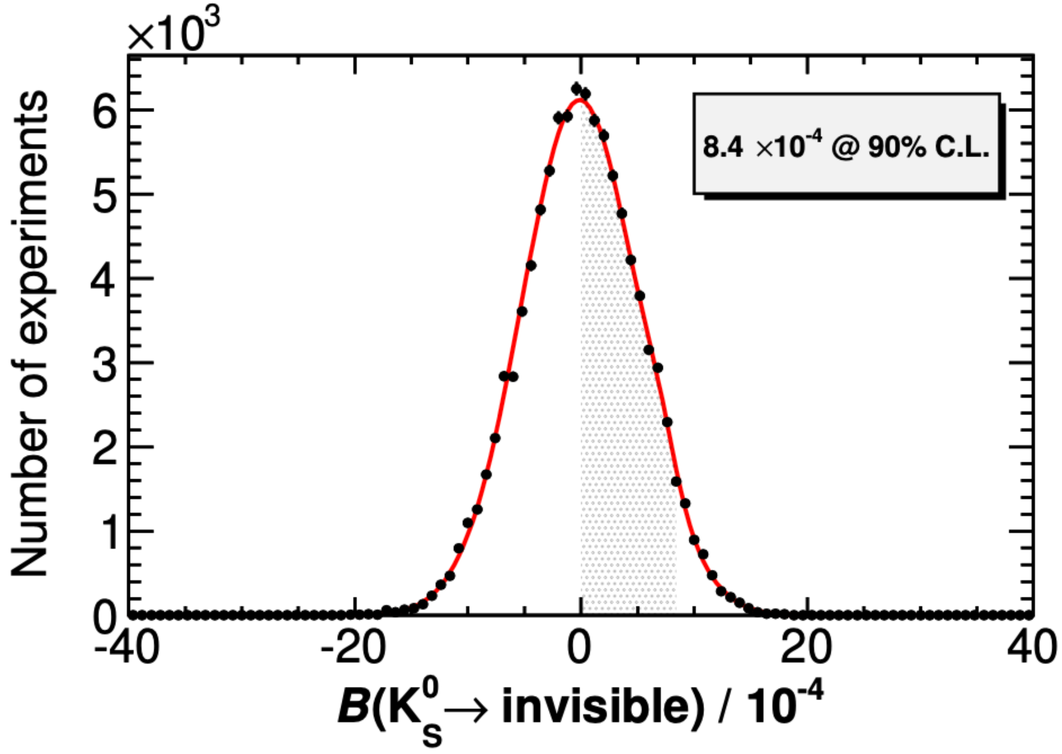
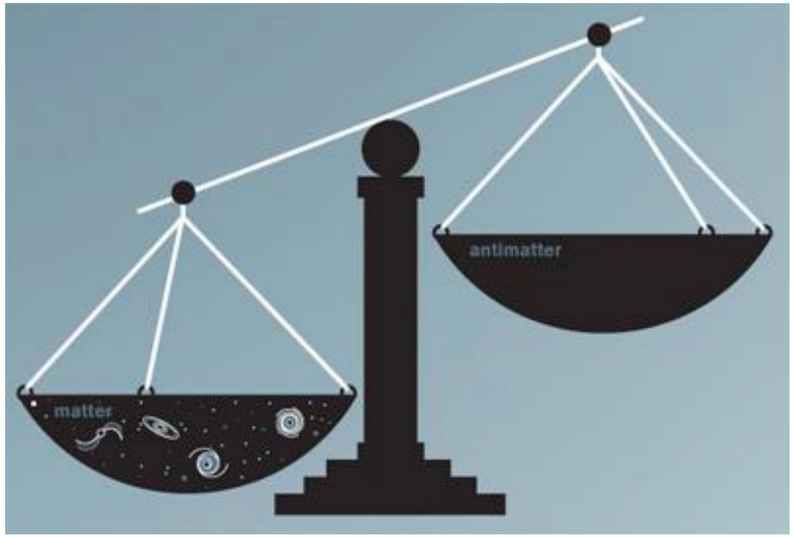
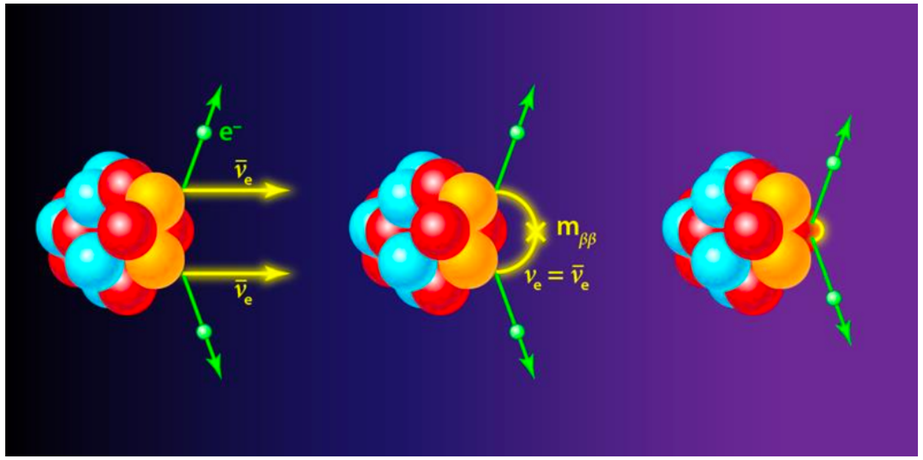


Fig 1. The resulting distribution of the calculated B($K_S^0 \to$ invisible) across these toy samples

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 extension $\Delta(B-L)=0$
- Furthermore, another BNV under dimension seven operators allow $\Delta(B-L)=2$
- lepton number violation helps us study neutrinos and whether they're Dirac or Majorana
- LNV can also be probed with hadron/lepton decays





Search for $\Lambda - \bar{\Lambda}$ oscillation in $J/\psi \to \Lambda\bar{\Lambda}$ decay

- Search for $\Lambda - \bar{\Lambda}$ oscillation in the decay $J/\psi \to \Lambda\bar{\Lambda}$, using 10.087 million J/ψ events at 3.097 GeV with the BESIII detector.
- No evidence of $\Lambda - \bar{\Lambda}$ oscillation in $J/\psi \to \Lambda\bar{\Lambda}$ decay are observed.
- Upper Limits (at 90% confidence level) for the oscillation probability, oscillation parameter, and oscillation time:
  - $P(\Lambda) \leq 1.4 \times 10^{-6}$
  - $\Delta m_{\Lambda\bar{\Lambda}} \leq 2.1 \times 10^{-18} GeV$
  - $\tau_{osc} > 3.1 \times 10^{-1} s$
- In comparison to the recent BESIII result, we have imposed more stringent constraints on the upper limits of the corresponding parameters.

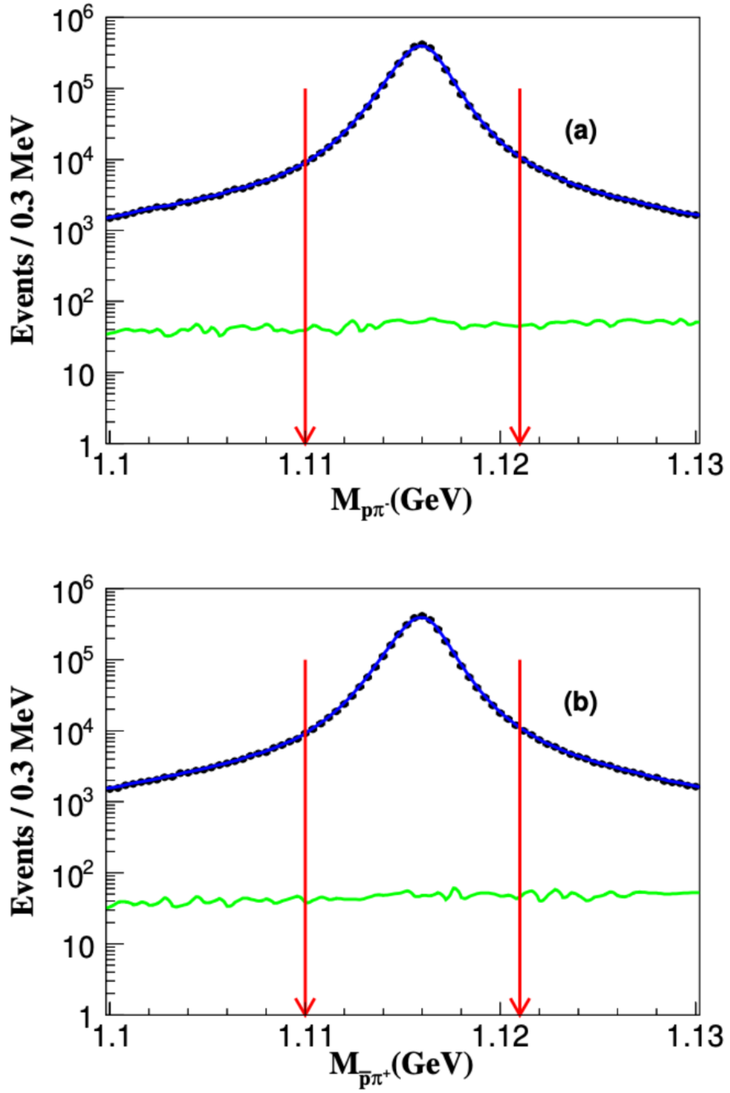


Fig 1. The simultaneous fit result

Search for lepton number violating decays of $D_s^+ \to h^- h^0 e^+ e^+$

- Search for LNV ($\Delta L = 2$) decays of $D_s^+ \to h^- h^0 e^+ e^+$ using 7.33 fb^{-1} of e^+e^- collision data (4.128 to 4.226 GeV).
- Also searched for Majorana neutrino in $D_s^+ \to \phi\pi^- e^+ e^+$ with various mass assumptions.
- No significant signal is observed for either search.
- Upper Limits (at 90% confidence level) for these branch fraction:
  - $B(D_s^+ \to \phi\pi^- e^+ e^+) < 6.9 \times 10^{-5}$
  - $B(D_s^+ \to \phi K^- e^+ e^+) < 9.9 \times 10^{-5}$
  - $B(D_s^+ \to K_S^0 \pi^- e^+ e^+) < 1.3 \times 10^{-5}$
  - $B(D_s^+ \to K_S^0 K^- e^+ e^+) < 2.9 \times 10^{-5}$
  - $B(D_s^+ \to \pi^- \pi^0 e^+ e^+) < 2.9 \times 10^{-5}$
  - $B(D_s^+ \to K^- \pi^0 e^+ e^+) < 3.4 \times 10^{-5}$
- For the decay $D_s^+ \to \phi e^+ \nu_m$, the upper limits of the branching fraction at the 90% C.L. with different m_{ν_m} in range of [0.20,0.80] GeV are between 10^{-5} and 10^{-2}.

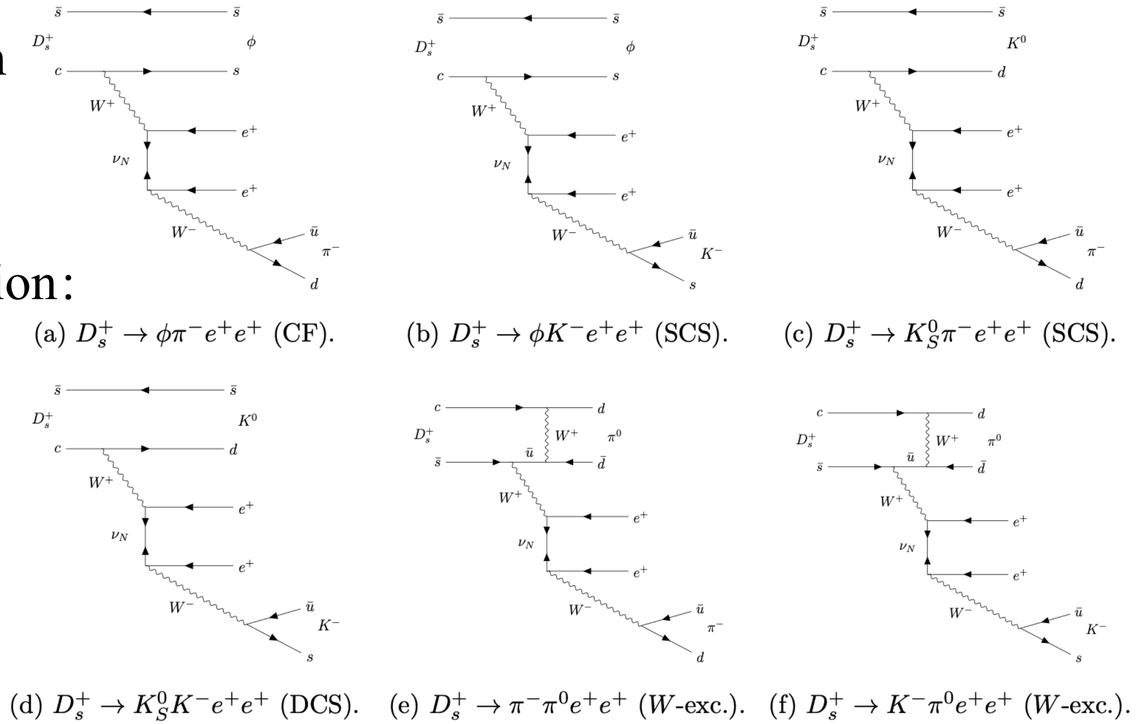


Fig 1. The Feynman diagrams for four-body LNV decays

Summary

- The rare decays and violating decays (LNV, BNV, FCNC) are essential to probe New Physics beyond the Standard ModelNew physics search at BESIII
- BESIII has great potential with unique datasets and advanced analysis techniques
- BESIII has collected $(10087 \pm 44) \times 10^6$ J/ψ and $(2712 \pm 14) \times 10^6$ $\psi(2S)$ events
- More & better results are coming soon!