Search for Charged Lepton Flavor Violation at BESIII

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On behalf of the BESIII Collaboration

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Outline

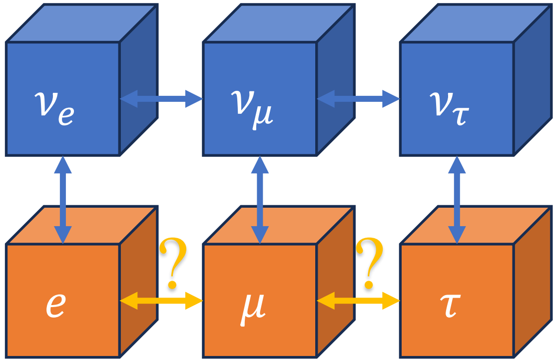
- Introduction
- BESIII and data sample
- J/ψ and $\psi(3686)$ CLFV decays
- Prospect and ongoing analysis
- Summary

Introduction

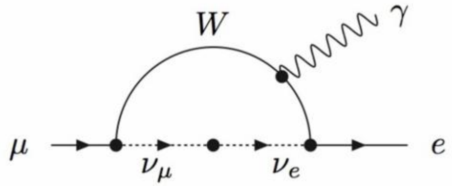
Charged Lepton Flavor Violation

Probe of new physics

Neutrino flavor violation is observed

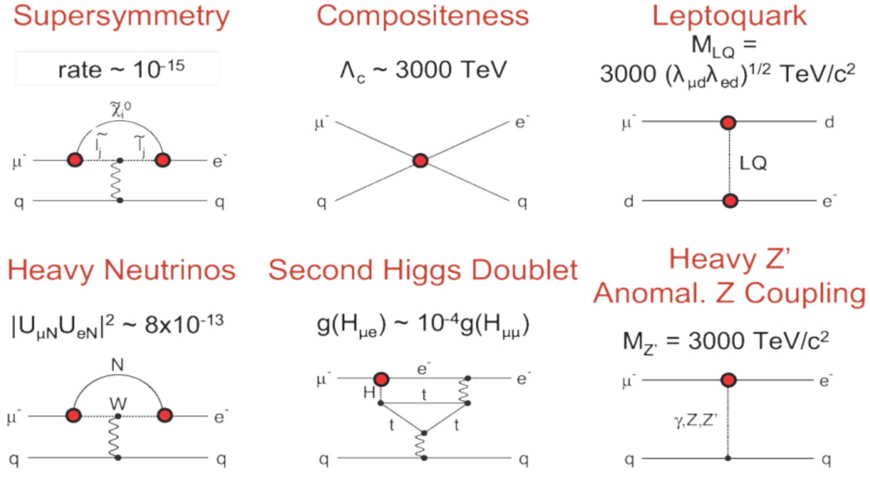


(neutrino oscillation)



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

Charged lepton flavor violation ?



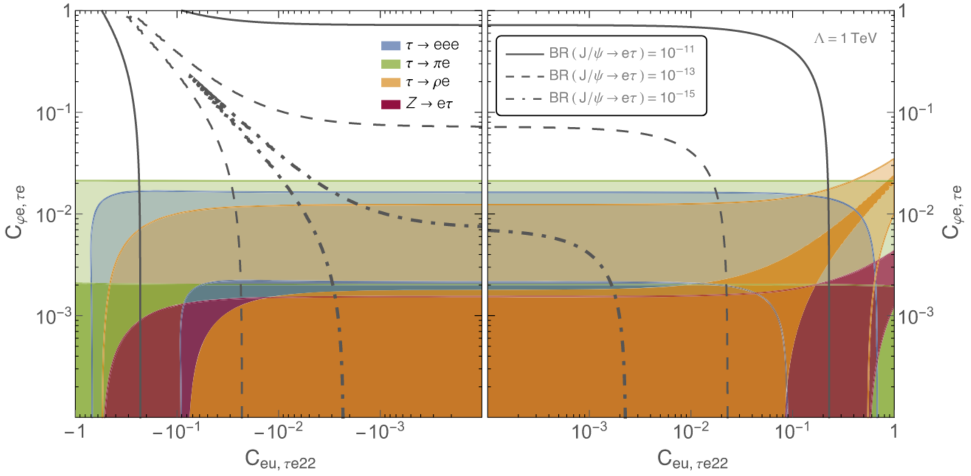
Theoretical model of CLFV

- Many **New Physics models** enhance CLFV effects up to a detectable level
  - SUSY particles
  - Top-quark condensation
  - ……

Phys. Rev. D 62, 073007 (2000)
Rev. Mod. Phys. 71, 513
Phys. Rev. D 106, 115039 (2022)

- **Effective Field Theory (EFT)**
  - Upper limit of Wilson coefficients
  - Energy scale of new physics

Phys. Rev. D 94, 074023 (2016)



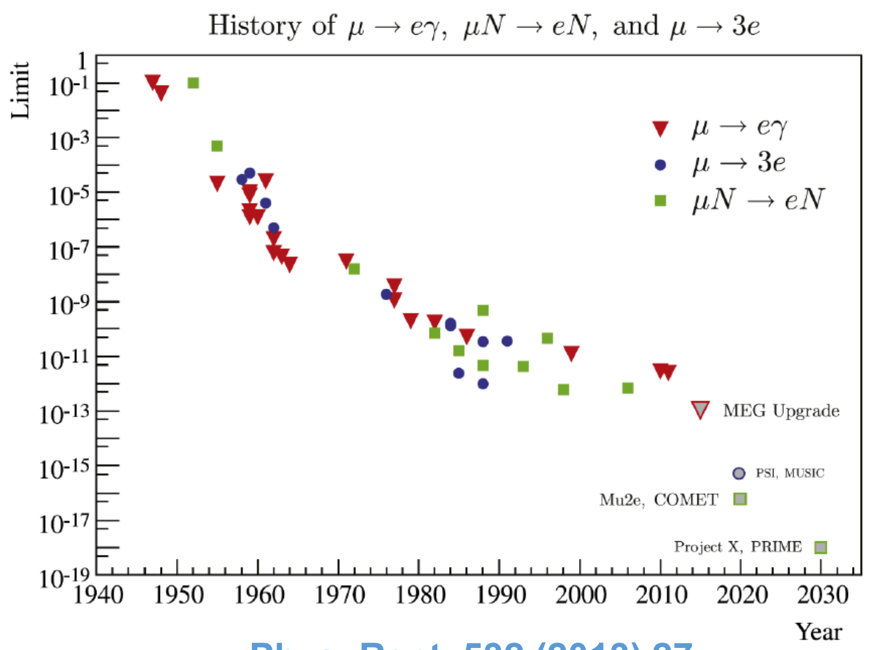
CLFV experimental research

Experimental searches in leptons (μ, τ), pseudoscalar mesons (K, π, B), vector mesons $(\phi, J/\psi, \Upsilon)$ and bosons (Z, H^0)

- $\mathcal{B}(\mu^+ \to e^+\gamma) < 3.1 \times 10^{-13}$ @90% CL — MEG II — Eur. Phys. J. C 84, 1042(2024)
- $\mathcal{B}(\tau^+ \to e^+\gamma) < 3.3 \times 10^{-8}$ @90% CL — BABAR — Phys. Rev. Lett. 104, 021802(2010)
- $\mathcal{B}(\mu \to 3e) < 1.0 \times 10^{-12}$ @90% CL — SINDRUM — Nucl. Phys. 562 B299, 1(1988)
- $\mathcal{B}(Z \to e^\pm\mu^\mp) < 2.62 \times 10^{-7}$ @95% CL — ATLAS — Phys. Rev. D 90, 072010 (2014)
- $\mathcal{B}(H^0 \to e^\pm\mu^\mp) < 4.7 \times 10^{-5}$ @95% CL — CMS — Phys. Lett. B 801, 135148 (2020)
- $\mathcal{B}(\phi \to e^\pm\mu^\mp) < 2 \times 10^{-6}$ @90% CL — SND — Phys. Rev. D 81, 057102 (2010)
- $\mathcal{B}(\Upsilon(1S) \to e^\pm\mu^\mp) < 3.6 \times 10^{-7}$ @90% CL — Belle — J. High Energ. Phys. 2022, 95 (2022)
- $\mathcal{B}(J/\psi \to e^\pm\tau^\mp) < 7.1 \times 10^{-8}$ @90% CL — BESIII
- $\mathcal{B}(J/\psi \to e^\pm\mu^\mp) < 4.5 \times 10^{-9}$ @90% CL — BESIII
- $\mathcal{B}(\psi(3686) \to e^\pm\mu^\mp) < 1.4 \times 10^{-8}$ @90% CL — BESIII
- …

Prospect on future experiments

- Mu2e & COMET: $\mu N \to eN$
  - Improve current limit by a factor of 10^4
  - Search for New Physics with mass scale up to $10^4\ TeV$
  - Next goal: $< 6 \times 10^{-17}$@ 90% $C.L.$
- MEGII & Mu3e: similar beam requirements
  - Intensity $\mathcal{O}(10^8\ muon/s)$, low momentum $p = 28\ MeV/c$
  - MEGII aiming at sensitivity down to 6×10^{-14} @ 90% $C.L.$

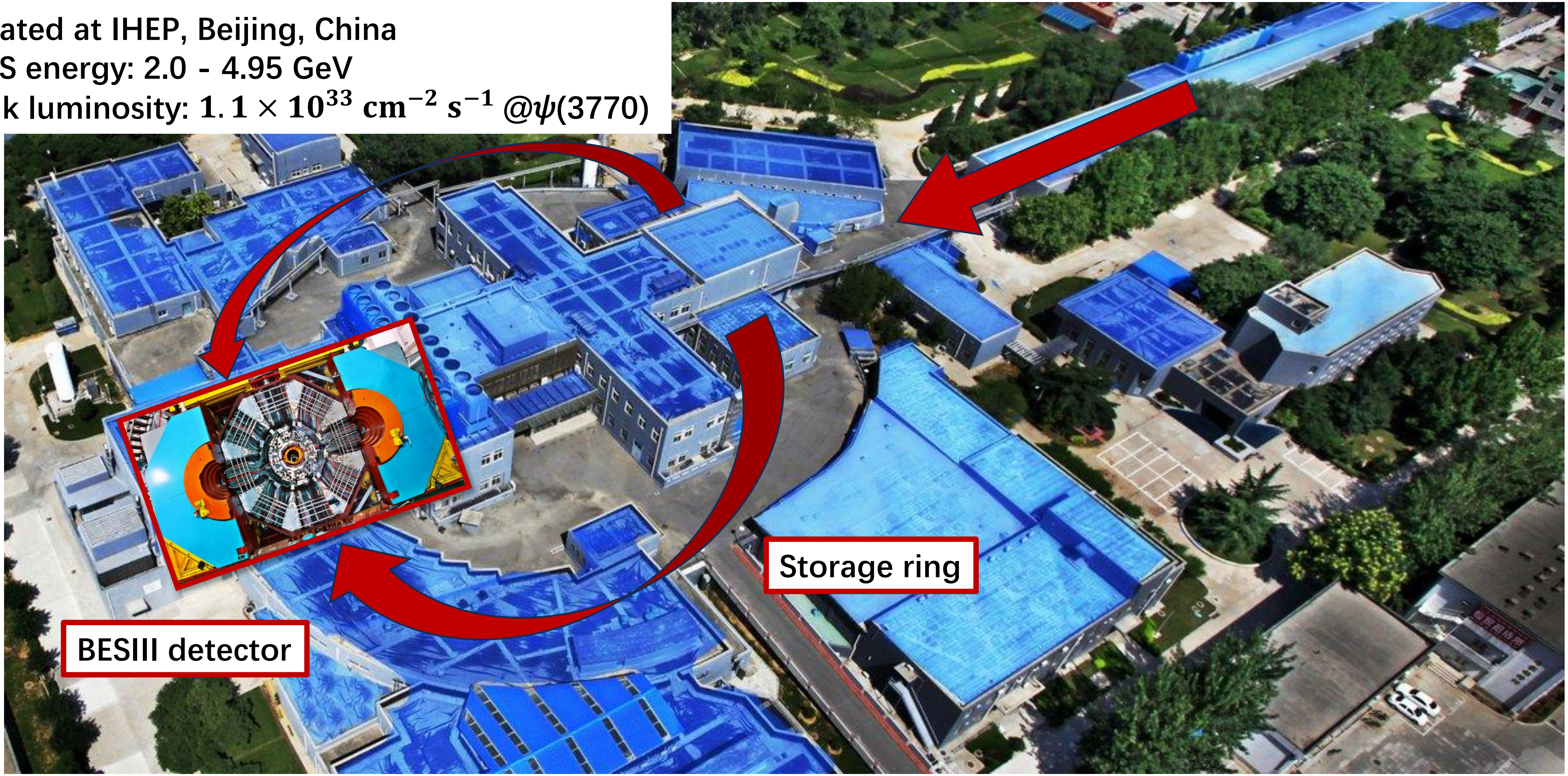


Phys. Rept. 532 (2013) 27

BESIII experiment

BEPCII

Located at IHEP, Beijing, China
CMS energy: 2.0 - 4.95 GeV
Peak luminosity: $1.1 \times 10^{33}\ \mathrm{cm^{-2}\ s^{-1}}$ @$\psi(3770)$

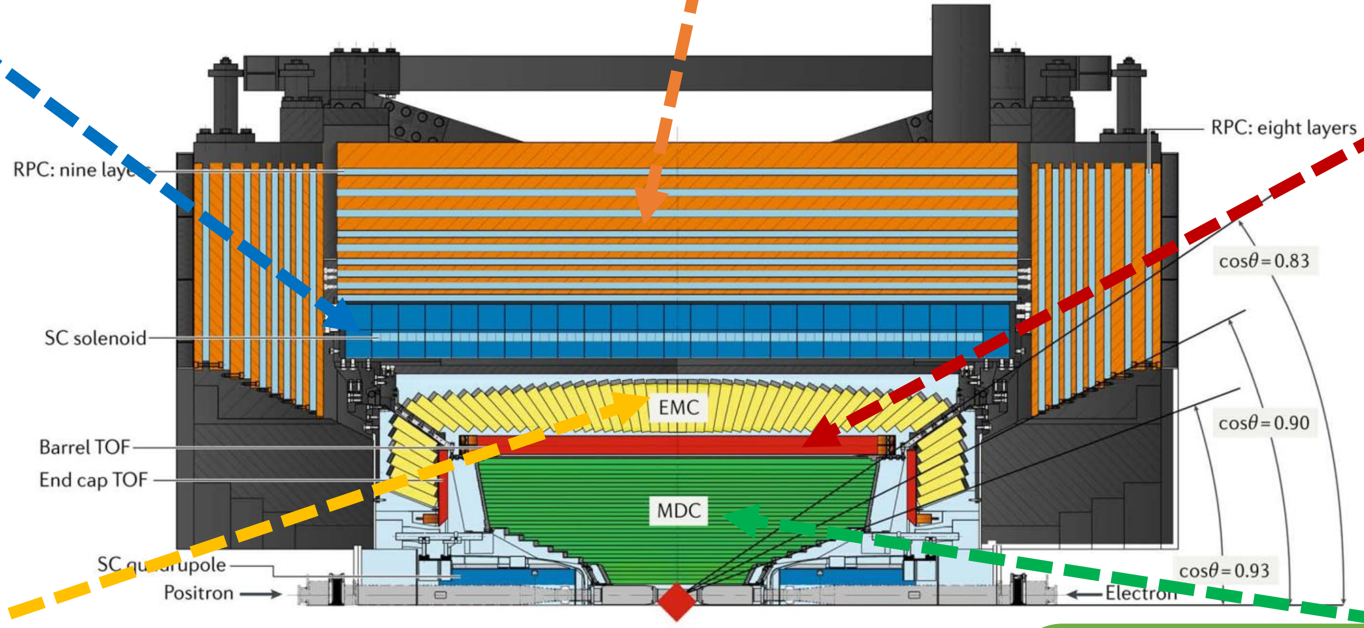


BESIII

Superconducting solenoid
- 1.0 T

Muon Counter (MUC)
- 9 layers (barrel) + 8 layers (end-cap)

Time Of Flight (TOF)
- $\sigma_t = 68$ ps (barrel)
- $\sigma_t = 60$ ps (end cap)



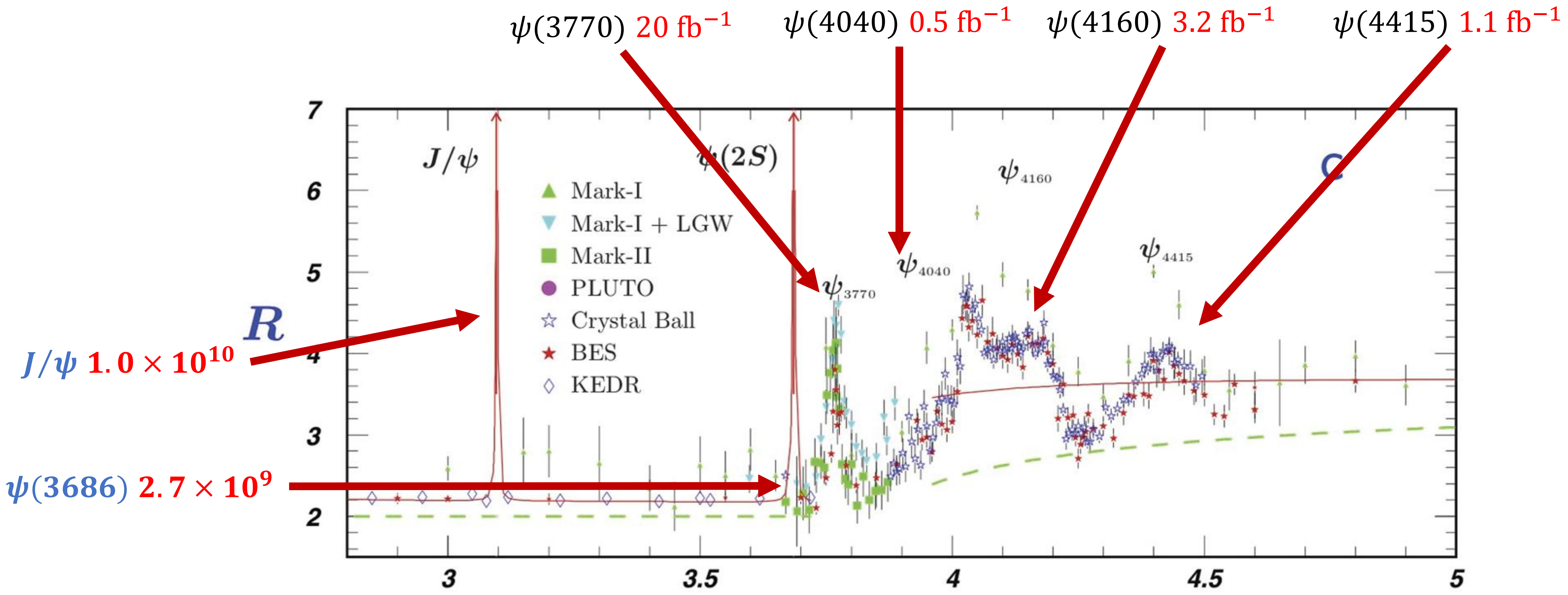
Electromagnetic Calorimeter (EMC)
- $\Delta E/E = 2.5\%$ @ 1.0 GeV
- $\sigma_{\phi z} = 0.6\ cm$ @ 1.0 GeV

Main Drift Chamber (MDC)
- $\sigma_{xy} = 130$ μm
- $\Delta P/P = 0.5\%$ @ 1.0 GeV
- $\sigma_{dE/dx} = 6 - 7\%$

Nucl. Instrum. Meth. A 614, 345 (2010)

BESIII charmonium data

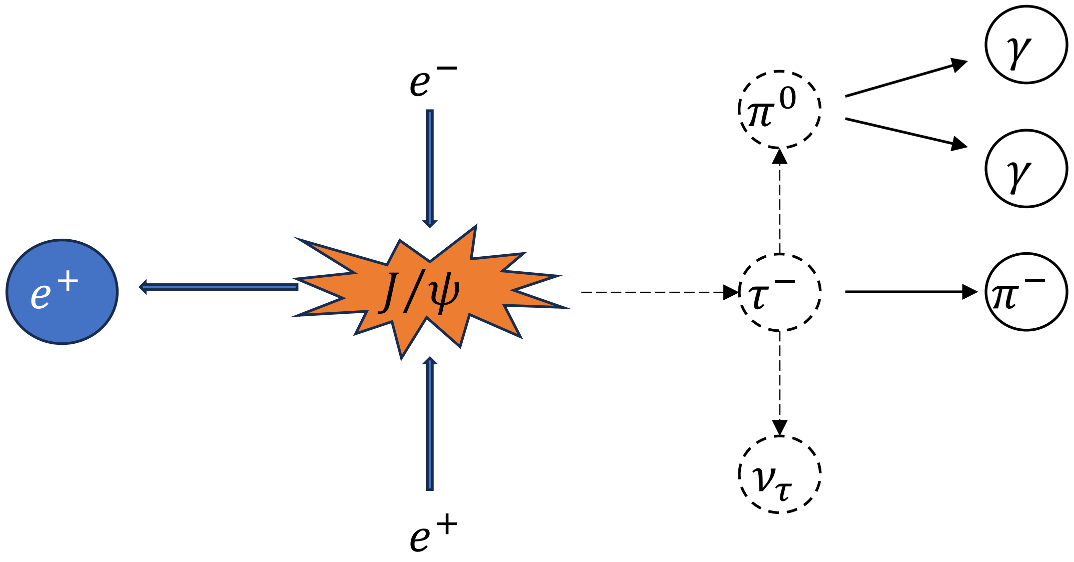
- BESIII has collected the largest data samples of J/ψ and $\psi(3686)$ on-threshold in the world

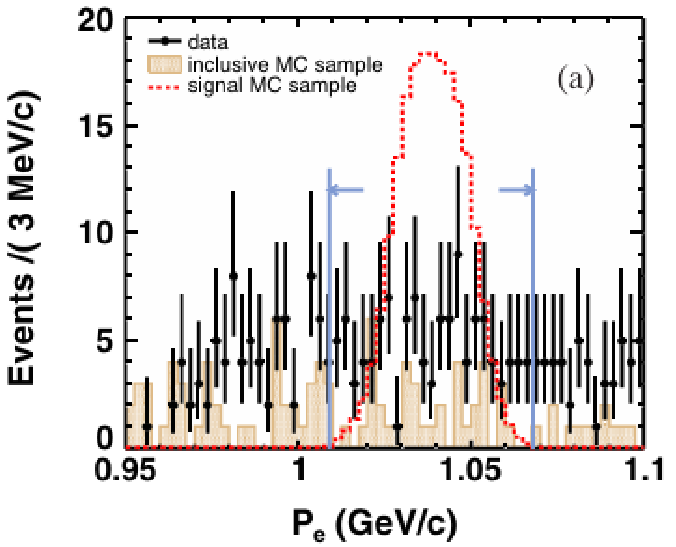


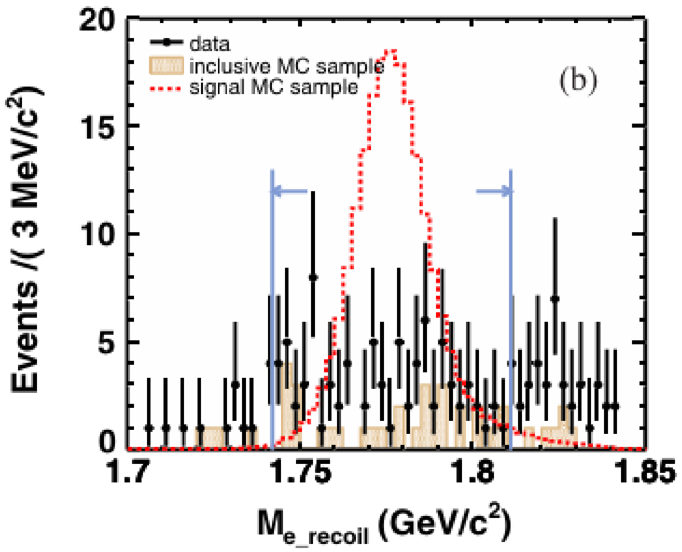
J/ψ and $\psi(3686)$ CLFV decays

$$\boldsymbol{J/\psi \to e\tau}$$

- **Analyzing 10 billion J/ψ data at BESIII**
  - Data sample I: 1310.6 Million J/ψ in 2009 and 2012
  - Data sample II: 8774.0 Million J/ψ in 2018 and 2019
- **Decay topology: $J/\psi \to e\tau, \tau \to \pi\pi^0\nu_\tau$**
  - Select one electron and one charged pion
  - At least two photon showers $\to \pi^0$
  - Monochromatic electron: P_e and M_{e_recoil}
  - One undetected neutrino with missing energy $E_{miss} > 0.43$ GeV



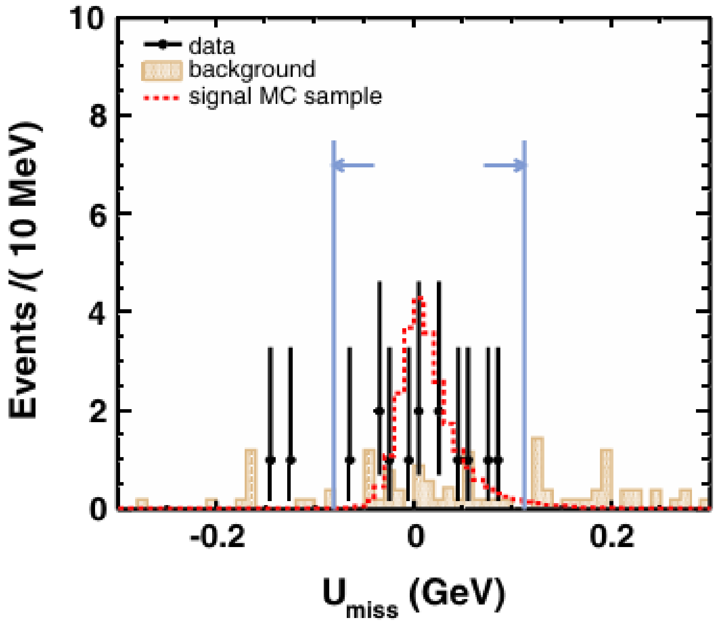




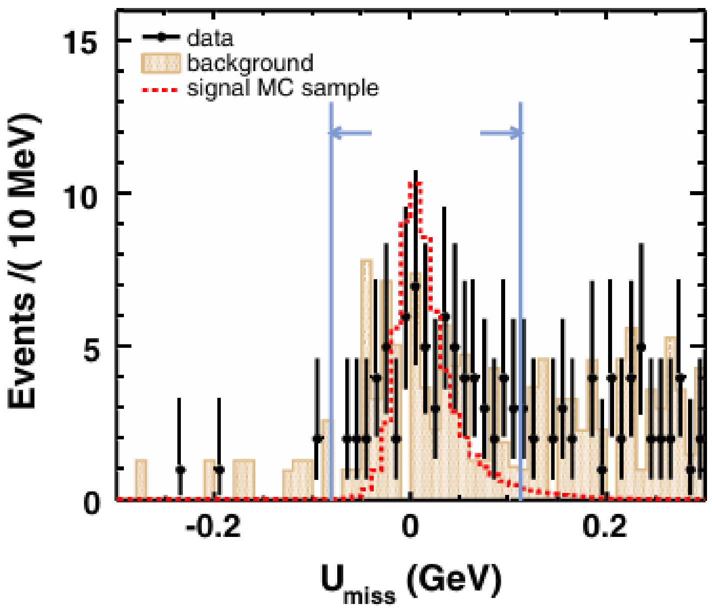
Analysis method

Phys. Rev. D 103, 112007 (2021)

- **signal region:** $-0.081\ \text{GeV} < U_{miss} < 0.112\ \text{GeV}$
  - Missing energy $E_{miss} = E_{CMS} - E_e - E_\pi - E_{\pi^0}$
  - $U_{miss} = E_{miss} - c|\vec{P}_{miss}|$
- **13(69) candidate events are observed in data sample I (II)**
  - Expected number of background events in data sample I (II): $N_{bkg} = 6.9(63.6)$



Data sample I



Data sample II

Background study & signal efficiency

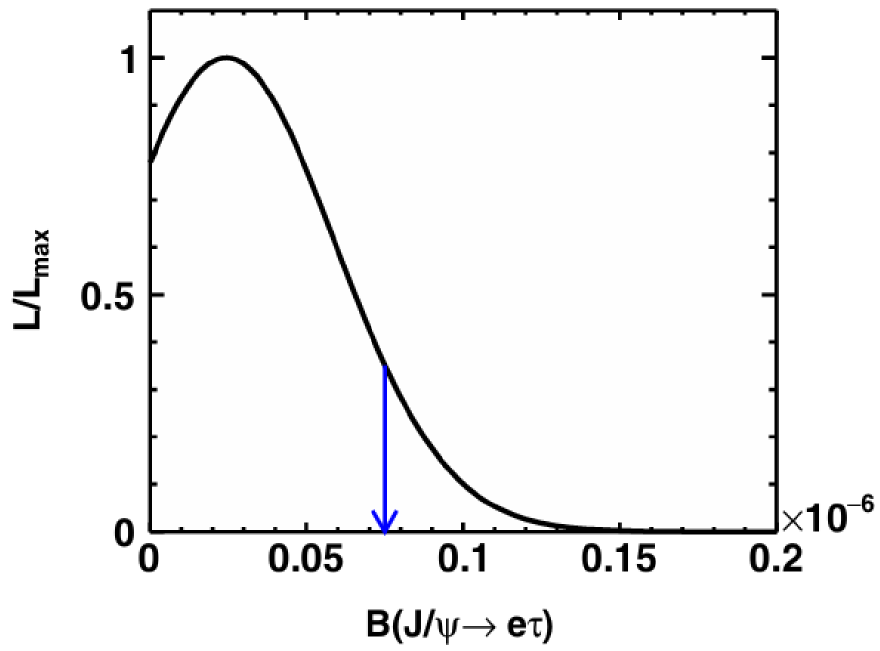
Phys. Rev. D 103, 112007 (2021)

- **Continuum background (radiative Bhabha)**
  - Control sample: $150\ \mathrm{pb}^{-1}$ $\sqrt{s} = 3.08$ GeV and $2.93\ \mathrm{fb}^{-1}$ $\sqrt{s} = 3.773$ GeV
  - Normalized by $1/s$ (uncertainty has been considered)
  - $\boldsymbol{N_{cont} = 5.8 \pm 1.8(37.9 \pm 11.5)}$ for data sample I (II)
- **J/ψ decay background**
  - Inclusive MC + exclusive MC ($J/\psi \to \pi^+\pi^-\pi^0, \rho\pi, \omega f_2(1270), \bar{p}n\pi^+$)
  - The uncertainty in J/ψ decay modeling is estimated as $\sim 16\%$
  - $\boldsymbol{N_{bkg}^{J/\psi} = 1.1 \pm 0.8(25.7 \pm 6.4)}$ for data sample I (II)
- **Signal efficiency**
  - Signal efficiency: $\boldsymbol{\epsilon_{signal} = (20.24 \pm 0.05)\%\ ((19.37 \pm 0.02)\%)}$ for data sample I (II)
  - Systematic uncertainties: $\boldsymbol{\sigma_{eff} = 3.9\%\ (4.1\%)}$ for data sample I(II)

Sources	Sample I	Sample II
Number of J/ψ	0.5%	0.4%
Quoted BF*	0.4%	0.4%
MC model	0.6%	...
Pion PID*	1.0%	1.0%
Pion tracking*	1.0%	1.0%
Electron PID	0.4%	0.9%
Electron tracking*	0.1%	0.1%
Photon detection*	1.0%	1.0%
π^0 reconstruction*	1.0%	1.0%
P_e and M_{e_recoil} requirements	3.0%	3.3%
E_{miss} requirement	1.0%	0.8%
Total uncertainty	3.9%	4.1%

- **Maximum likelihood estimator:**
  - Parameter of interest $\mathcal{B}(J/\psi \to e\tau)$
  - Nuisance parameters $\theta = (\epsilon_{eff}, N_{bkg})$
- $\boldsymbol{\mathcal{B}(J/\psi \to e\tau) < 7.5 \times 10^{-8}}$ **@ 90% C.L.**
  - Improve the previous best limit by **two orders of magnitude**
  - Comparable with the theoretical prediction
    - Theoretical prediction: $\mathbf{10^{-9}}$
    - Model-independent method
    - Unparticle physics
    - Minimal supersymmetric model with gauged baryon number and lepton number

$$\mathcal{L}(\mathcal{B}(J/\psi \to e^{\pm}\tau^{\mp}), \theta)$$
$$= P\left(N_{obs}, \mathcal{B}(J/\psi \to e^{\pm}\tau^{\mp}) \cdot N_{J/\psi} \cdot \mathcal{B}_{\tau^{\mp}\to\pi^{\mp}\pi^{0}\nu_{\tau}} \cdot \epsilon_{eff} + N_{bkg}\right)$$
$$\cdot G(\epsilon_{eff}^{mc}, \epsilon_{eff}, \sigma_{eff}^{mc})$$
$$\cdot G(N_{bkg}^{exp}, N_{bkg}, \sigma_{bkg}^{exp})$$



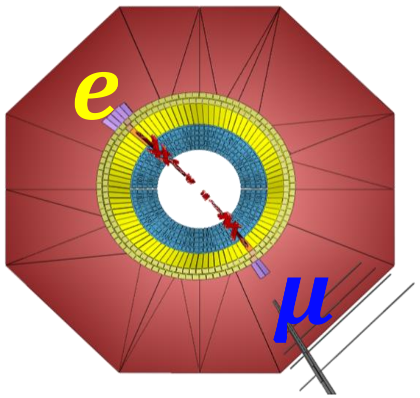
Phys. Rev. D 63, 016003 (2000)
Phys. Rev. D 83, 115015 (2011)
Mod. Phys. Lett. A 27, 1250172 (2012)
Phys. Rev. D 97, 056027 (2018)

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

$J/\psi \rightarrow e\mu$

Sci. China-Phys. Mech 221011 (2023) 66

- **Analyzing $(8.998 \pm 0.040) \times 10^9$ J/ψ events (without 2012 data)**
- **Decay topology: $J/\psi \rightarrow e\mu$**
- **Select two back-to-back oppositely charged tracks**
  - To reject cosmic rays, TOF timing difference $< 1.0\ ns$
  - Acollinearity angle $|\Delta\theta| = |180^\circ - (\theta_1 + \theta_2)| < 1.2^\circ$
  - Acoplanarity angle $|\Delta\phi| = \big|180^\circ - |\phi_1 + \phi_2|\big| < 1.5^\circ$
- **Utilizing dE/dx, deposited energy and MUC hit information for PID**

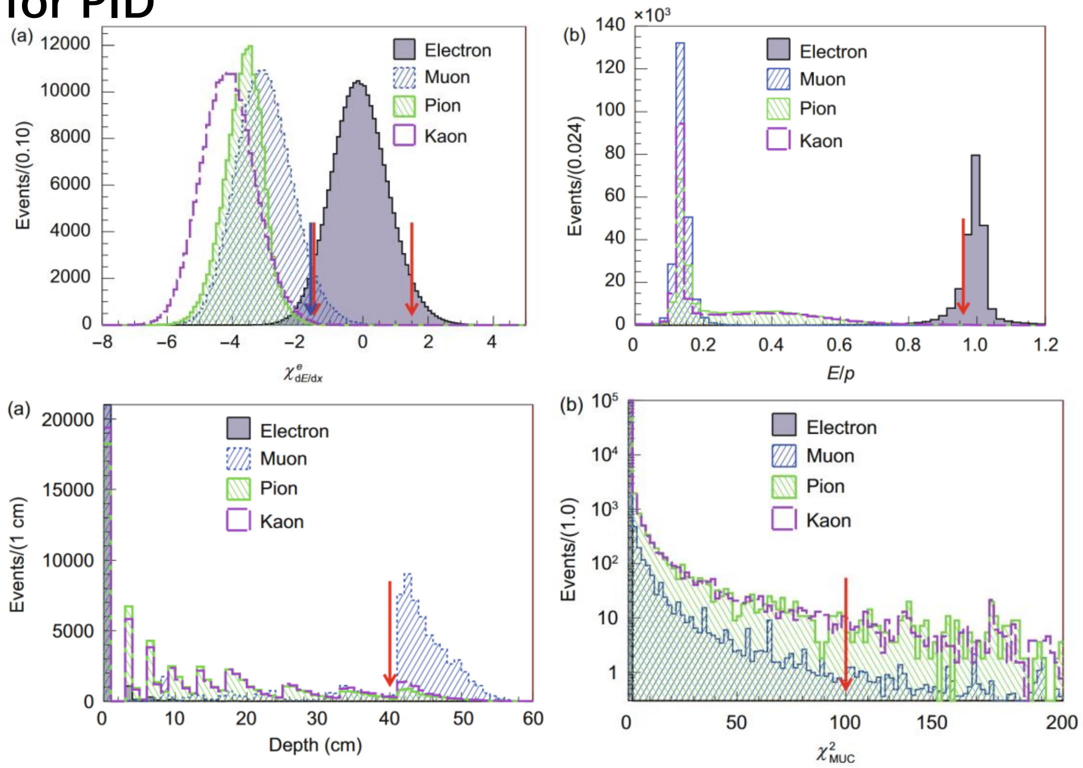


Electron ID

- Not associated in the MUC
- $-1.5 < \chi^e_{dE/dx} < 1.5$
  - $\chi^e_{dE/dx}$: the difference between measured and expected dE/dx under the electron hypothesis normalized by the dE/dx resolution
- $E/P > 0.96$
  - E: the deposited energy in the EMC;
  - P: the modulus of the momentum measured from MDC

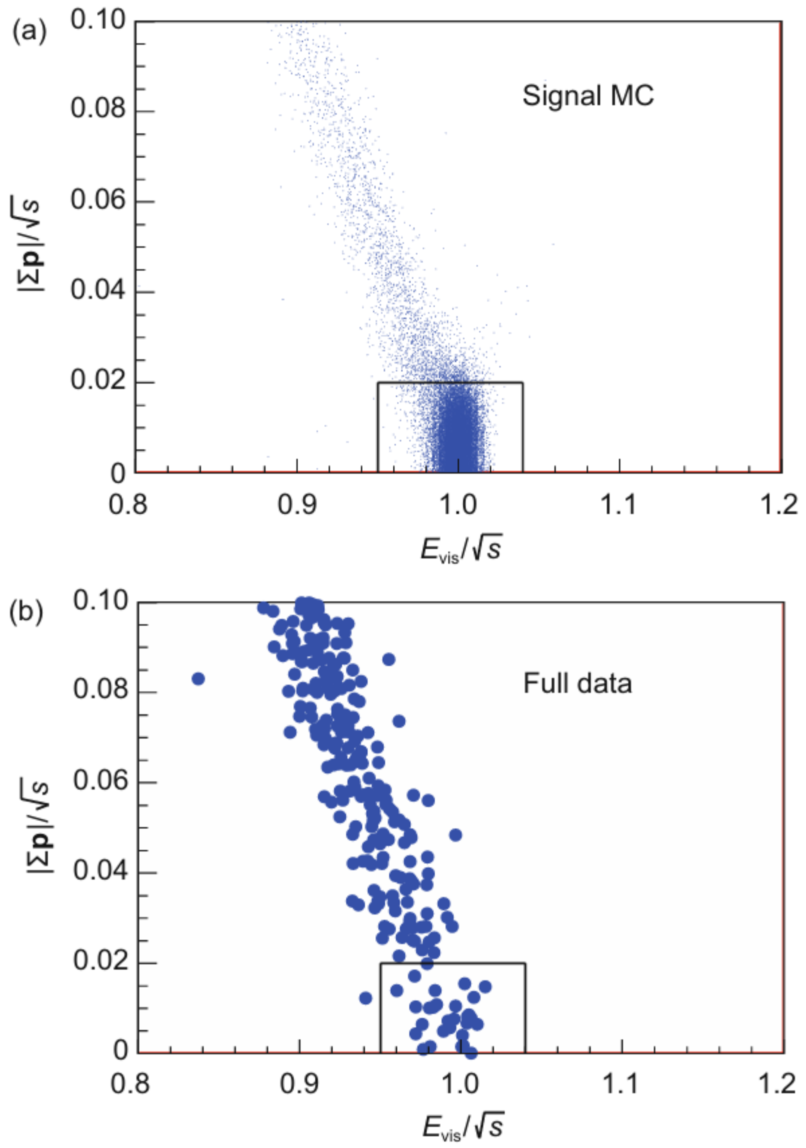
Muon ID

- $0.1 < E < 0.3\ GeV$, $\chi^e_{dE/dx} < -1.6$
- The penetration depth of the track in the MUC > 40 cm
- Each candidate track must penetrate more than three layers in the MUC, and $\chi^2_{MUC} < 100$



Analysis method

- **Signal region: $|\sum\vec{p}|/\sqrt{s} \le 0.02$ and $0.95 \le E_{vis}/\sqrt{s} \le 1.04$**
  - $|\sum\vec{p}|$: The magnitude of the vector sum of the momenta, in signal events it should be ~ 0
  - E_{vis}: The total reconstructed energy of e and μ
  - $\sqrt{s}$: Center-of-mass energy, so in signal events $E_{vis}/\sqrt{s} \sim 1$
  - about 85% of the signal events fall into the signal region
- **29 candidate events are observed in data sample**
  - Consistent with the background events estimation in the signal region: $N^{S}_{bkg1} + N^{S}_{bkg2} = 36.8$



Background study and signal efficiency

Sci. China-Phys. Mech 221011 (2023) 66

- **Continuum background ($e^+e^- \to e^+e^-(\gamma), \mu^+\mu^-(\gamma)$)**
  - Control sample: $\sqrt{s} = 3.773$ GeV, 3.510 GeV, 3.080 GeV
  - $1/s$ energy-dependence of cross section
  - $N_{bkg2}^{norm} = 12.0 \pm 3.7$

- **J/ψ decay background**
  - Inclusive MC + exclusive MC ($J/\psi \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, K^+K^-, p\bar{p}$)
  - $N_{bkg1}^{norm} = 24.8 \pm 1.5$

- **Detection efficiency: $(21.18 \pm 0.13)\%$**
  - Systematic uncertainties: **14%**

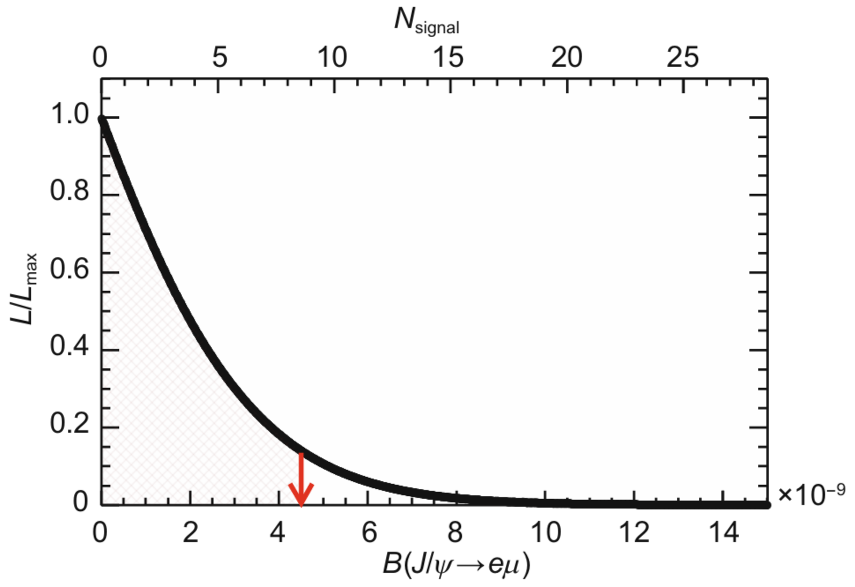
Sources	Systematic uncertainty
Tracking and PID efficiency	13%
TOF timing	0.52%
Photon veto	0.83%
$\lvert\Delta\theta\rvert$ and $\lvert\Delta\phi\rvert$ requirements	2.6%
Total	**14%**

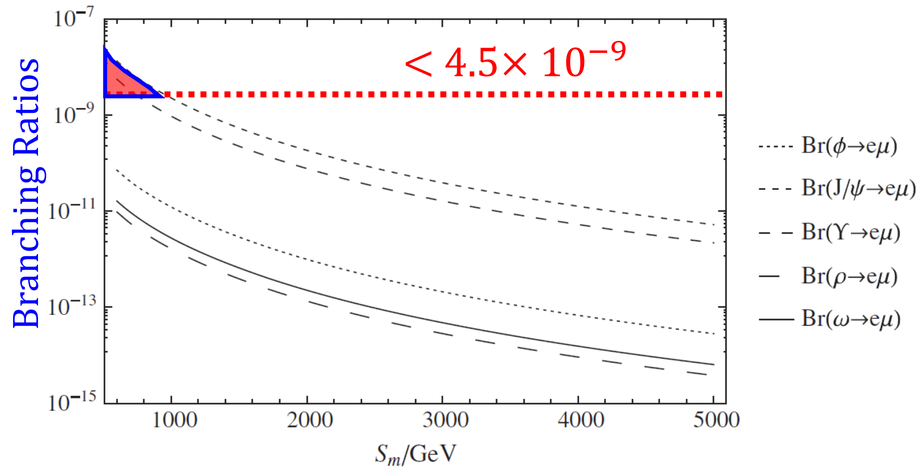
Upper limit result

- **Maximum likelihood estimator**
  - ➢ Parameter of interest $\mathcal{B}(J/\psi \to e\mu)$
  - ➢ Nuisance parameters $\theta = (\epsilon_{sig}, N_{J/\psi}, N_{bkg1}, N_{bkg2})$

$$\mathcal{L}(\mathcal{B}, \epsilon_{sig}, N_{J/\psi}, N_{bkg1}, N_{bkg2}) = \mathcal{P}(N_{obs} | N_{J/\psi} \cdot \mathcal{B} \cdot \epsilon_{sig} + N_{bkg1} + N_{bkg2}) \cdot \mathcal{G}(\epsilon_{sig} | \epsilon_{sig}^{MC}, \epsilon_{sig}^{MC} \cdot \sigma_{sig}^{EFF}) \cdot \mathcal{P}\left(N_{bkg1}^{J/\psi-MC} \middle| N_{bkg1}/f_1\right) \cdot \prod_k \left(\mathcal{P}(N_{cont}^k | N_{bkg2}/f_2^k)\right) \cdot \mathcal{G}\left(N_{J/\psi} \middle| N_{J/\psi}^{data}, \delta N_{J/\psi}^{data}\right)$$

- $\mathcal{B}(J/\psi \to e\mu) < 4.5 \times 10^{-9}$ @ 90 % C.L.
  - ➢ Improve the previous limit by **a factor of more than 30**
  - ➢ The most stringent limit on CLFV in heavy quarkonium systems
  - ➢ Provides constraints on the parameter spaces of new physics models





Sensitive parameters, Diagonal elements in $m_{\tilde{L}}, m_{\tilde{R}}$

Phys. Rev. D 97, 056027 (2018)

$\psi(3686) \to e\mu$

$\psi(3686) \to e\mu$

arXiv:2507.10331

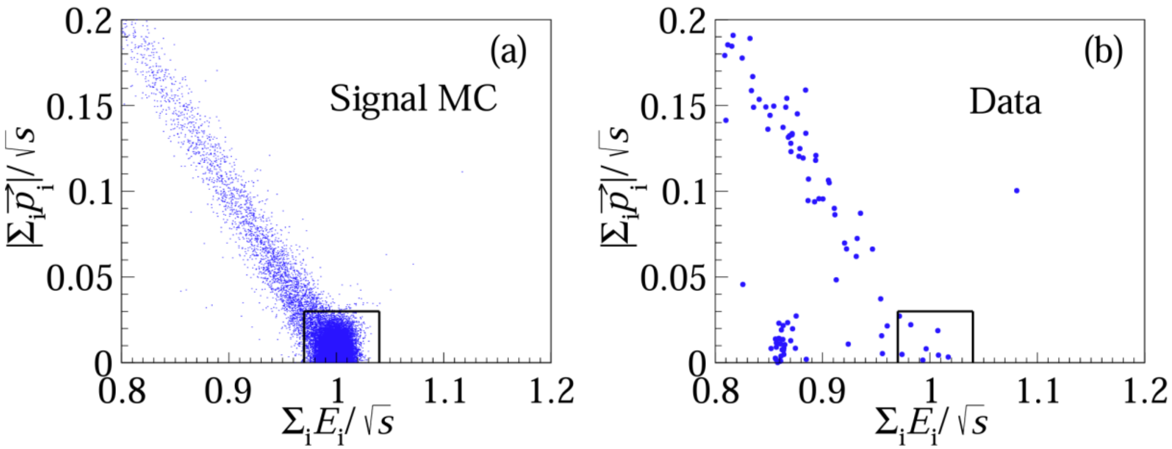
- **Analyzing $(2367.0 \pm 11.1) \times 10^6$ $\psi(3686)$ events at BESIII**
- **Decay topology: $\psi(3686) \to e\mu$**
- **Same analysis method as $J/\psi \to e\mu$**
- **Signal box:**
  - $|\sum\vec{p}|/\sqrt{s} \leq 0.03$
  - $0.97 \leq E_{vis}/\sqrt{s} \leq 1.04$

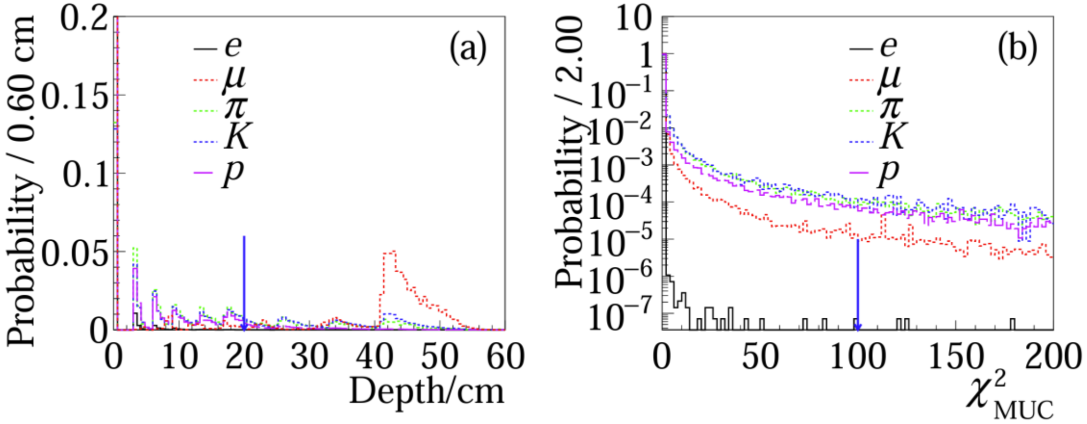
Electron ID

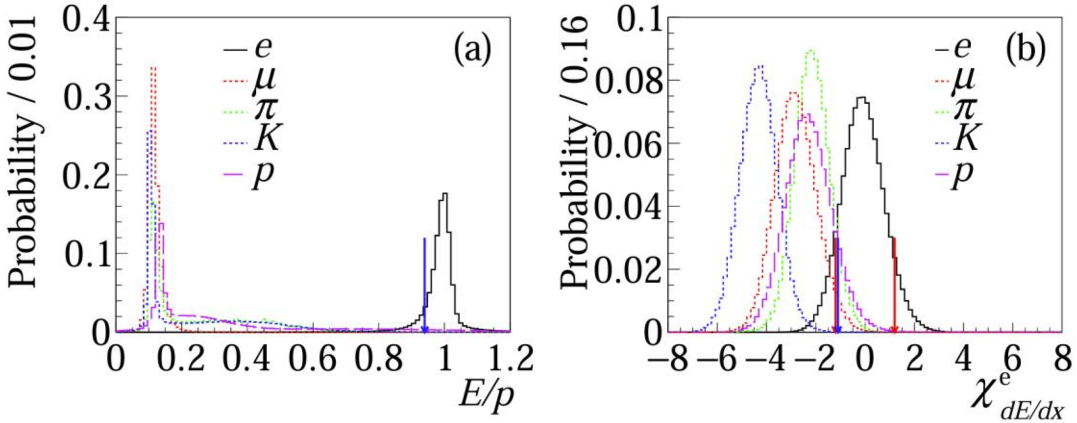
- $-1.2 < \chi^e_{dE/dx} < 1.2$
- $E/P > 0.94c$

Muon ID

- $0.1 < E < 0.3\ GeV$, $\chi^e_{dE/dx} < -1.1$
- $Depth_{MUC} > 20$ cm
- $\chi^2_{MUC} < 100$







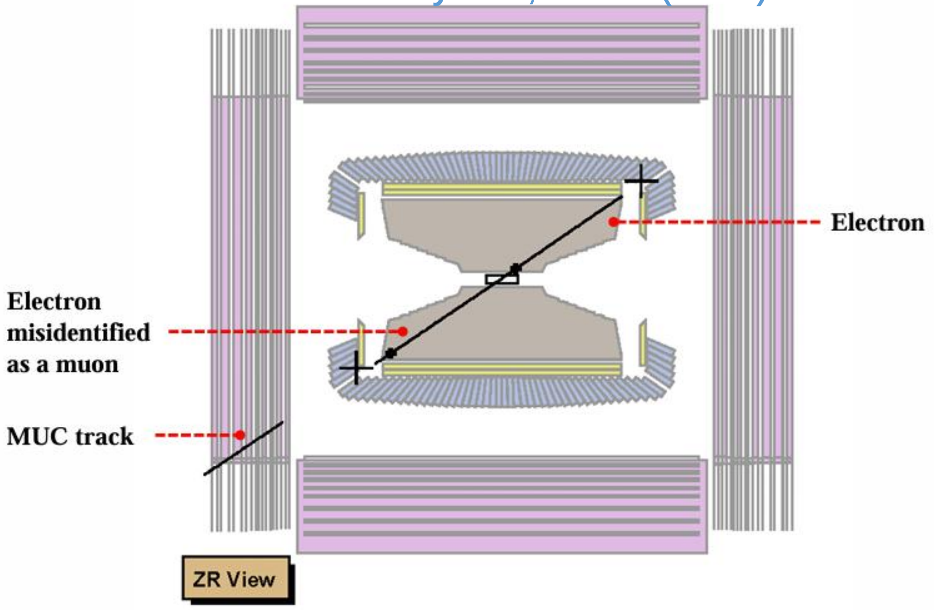
Background study and signal efficiency

arXiv:2507.10331

- **Selections to suppress background caused by EMC leakage**
  - Polar angle difference between the track in the MUC and MDC is required to be less than $20°$.
  - Azimuthal angle difference between the track in the MUC and MDC is required to be less than $30°$.

- **Continuum background ($e^+e^- \to e^+e^-(\gamma), \mu^+\mu^-(\gamma)$)**
  - Control sample: $\sqrt{s} = 3.65\ \mathrm{GeV}, 3.682\ \mathrm{GeV}, 3.773\ \mathrm{GeV}$
  - $1/s$ energy-dependence of cross section
  - $N^s_{bkg2} = 1.6$
- **$\psi(3686)$ decay background**
  - Inclusive MC + exclusive MC ($\psi(3686) \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-, K^+K^-, p\bar{p}$)
  - $N^s_{bkg1} = 4.6$
- **Detection efficiency: $(24.18 \pm 0.16)\%$**
  - Systematic uncertainty: 11.4%
- **8 candidate events are observed in data sample**
  - **Expected background events number: $N^s_{bkg1} + N^s_{bkg2} = 6.2$.**

Front. Phys. 19, 64201 (2024)



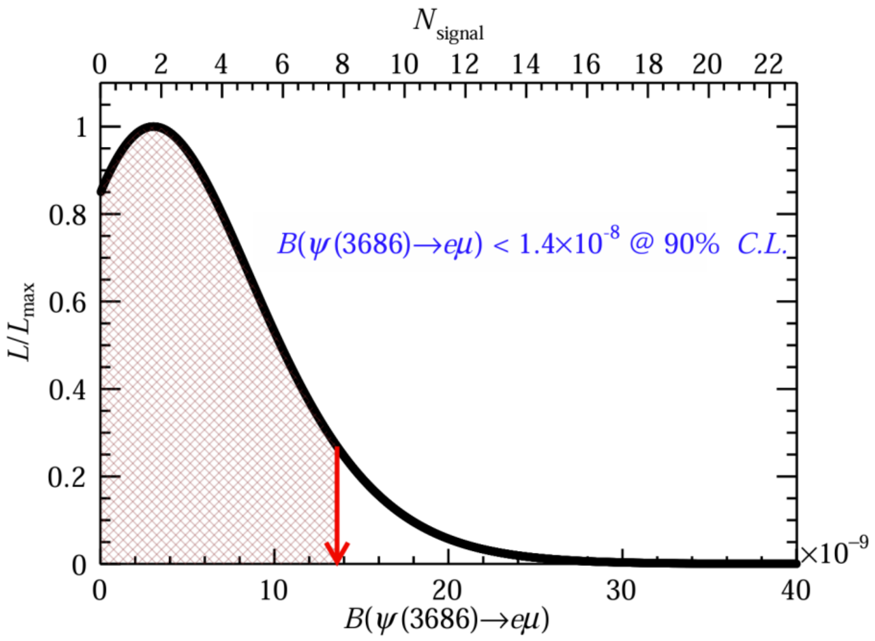
Source	Uncertainty(%)
Tracking and PID of electrons and muons	0.5
TOF difference requirement	0.2
Photon veto	1.1
$\lvert\Delta\theta\rvert$ and $\lvert\Delta\phi\rvert$ requirement	3.8
Bhabha veto	3.3
Signal region	1.7
MC model	10.0
MC statistics	0.4
Number of $\psi(3686)$ events	0.5
Total	11.4

Upper limit result

arXiv:2507.10331

- **Maximum likelihood estimator**
  - Parameter of interest $\mathcal{B}(\psi(3686) \to e\mu)$
  - Nuisance parameters $\theta = (\epsilon_{sig}, N_{\psi(3686)}, N_{bkg1}, N_{bkg2})$

- $\boldsymbol{\mathcal{B}(\psi(3686) \to e\mu) < 1.4 \times 10^{-8}}$ **@ 90 % C.L.**
  - First upper limit on BF of $\psi(3686) \to e\mu$
  - Provides constraints on the parameter spaces of new physics models



$$
\begin{aligned}
\mathcal{L}(\mathcal{B}, \epsilon_{\rm sig}, N_{\psi(3686)}, N_{\rm bkg1}, N_{\rm bkg2}) = \\
& \mathcal{P}(N_{\rm obs}|N^{\rm data}_{\psi(3686)} \cdot \mathcal{B} \cdot \epsilon_{\rm sig} + N_{\rm bkg1} + N_{\rm bkg2}) \\
& \cdot \mathcal{G}(\epsilon_{\rm sig}|\epsilon^{\rm MC}_{\rm sig}, \epsilon^{\rm MC}_{\rm sig} \cdot \sigma^{\rm MC}_{\rm sig}) \\
& \cdot \mathcal{P}(N^{\psi(3686)-\rm MC}_{\rm bkg1}|N_{\rm bkg1}/f_1) \\
& \cdot \prod_k \mathcal{P}(N^k_{\rm cont}|N_{\rm bkg2}/f^k_2) \\
& \cdot \mathcal{G}(N_{\psi(3686)}, N^{\rm data}_{\psi(3686)}, \sigma_{N^{\rm data}_{\psi(3686)}}),
\end{aligned}
$$

Constraints on Wilson coefficients

Phys. Rev. D 94, 074023 (2016)

- **Effective field theory:** an effective Lagrangian (well integrate various new physical models)
- **Wilson coefficients:** calculated with single-operator dominance hypothesis, constrained by UL result from CLFV decays

$$\mathcal{L}_{\rm EFT} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda_{\rm odd}} \sum_i C_i^{(5)} \mathcal{O}_i^{D=5} + \frac{1}{\Lambda_{\rm even}^2} \sum_i C_i^{(6)} \mathcal{O}^{D=6} + \cdots .$$

$$\left|\frac{C_{DL}^{\ell_1\ell_2}}{\Lambda^2}\right| = \left|\frac{C_{DR}^{\ell_1\ell_2}}{\Lambda^2}\right| = \frac{\sqrt{4\pi\alpha}}{m_V^2 y(1-y^2)\sqrt{2y^2+1}} \cdot \sqrt{\frac{\mathcal{B}(V\to\ell_1\ell_2)/2}{\mathcal{B}(V\to e^+e^-)}},$$

$$\left|\frac{C_{VL}^{q\ell_1\ell_2}}{\Lambda^2}\right| = \left|\frac{C_{VR}^{q\ell_1\ell_2}}{\Lambda^2}\right| = \frac{4\pi\alpha|Q_q|}{\sqrt{2}\kappa_V m_V^2(1-y^2)} \cdot \sqrt{\frac{\mathcal{B}(V\to\ell_1\ell_2)/2}{\mathcal{B}(V\to e^+e^-)}},$$

$$\left|\frac{C_{TL}^{q\ell_1\ell_2}}{\Lambda^2}\right| = \left|\frac{C_{TR}^{q\ell_1\ell_2}}{\Lambda^2}\right| = \frac{4\pi\alpha|Q_q|}{2\kappa_V G_F m_q m_V^3 y(1-y^2)\sqrt{2y^2+1}} \cdot \sqrt{\frac{\mathcal{B}(V\to\ell_1\ell_2)/2}{\mathcal{B}(V\to e^+e^-)}}.$$

Wilson coef./GeV^{-2}	$\ell_1\ell_2$	J/ψ	$\psi(2S)$
$\left\|C_{DL/DR}^{\ell_1\ell_2}/\Lambda^2\right\|$	$e\mu$	1.8×10^{-4}	7.3×10^{-4}
	$e\tau$	5.0×10^{-5}	—
$\left\|C_{VL/VR}^{q\ell_1\ell_2}/\Lambda^2\right\|$	$e\mu$	1.8×10^{-6}	6.0×10^{-6}
	$e\tau$	1.1×10^{-5}	—
$\left\|C_{TL/TR}^{q\ell_1\ell_2}/\Lambda^2\right\|$	$e\mu$	0.80	2.7
	$e\tau$	0.23	—

Prospect and ongoing analyses

Ongoing analysis: $\chi_{cJ} \to e\mu$

BAM-00669

- Various quantum numbers have been searched for:
  - Vector states: $\phi, J/\psi, \Upsilon$;
  - Pseudoscalar states: π^0, η, η'
- Other quantum numbers (like χ_{cJ}, $J = 0,1,2$) haven't been search yet…

- **Using $(27.12 \pm 0.14) \times 10^8$ $\psi(3686)$ events collected with BESIII**
- **Search for $\chi_{cJ} \to e\mu$ with $\psi(3686) \to \gamma\chi_{cJ}$**

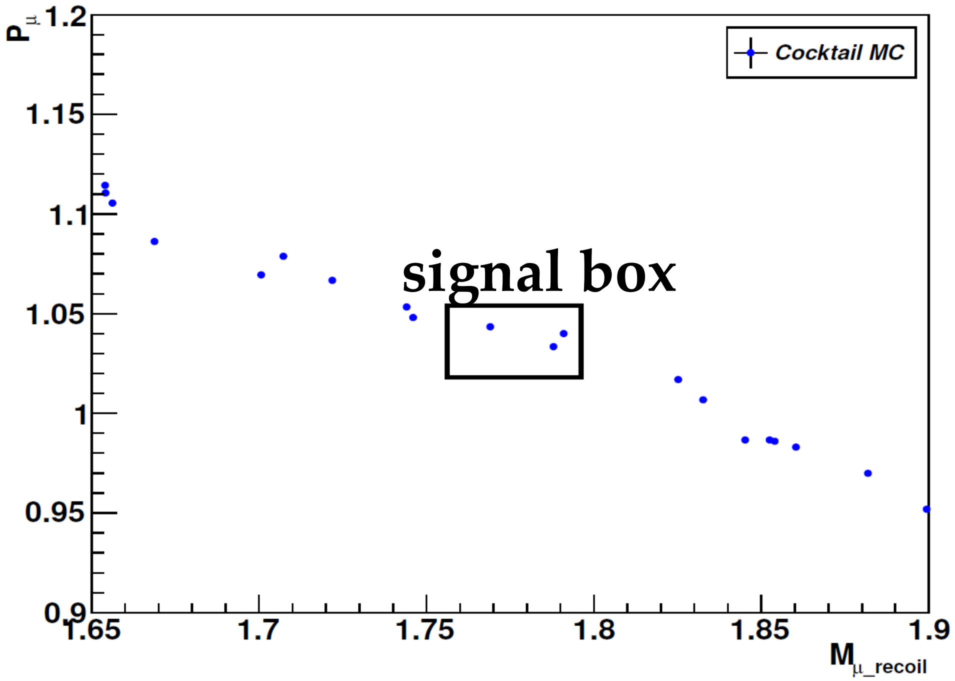
$$
\begin{aligned}
\mathcal{L} =& \mathcal{P}(N_{\rm obs}, \mathcal{B}_{\psi(3686)\to\gamma\chi_{cJ}} \times \mathcal{B} \times (N_{\psi(3686),\rm I} \times \epsilon_{\rm I} \\
&+ N_{\psi(3686),\rm II} \times \epsilon_{\rm II}) + \sum_i (N_{{\rm bkg,I},i} + N_{{\rm bkg,II},i})) \\
&\times \mathcal{G}(\mathcal{B}^{\rm nominal}_{\psi(3686)\to\gamma\chi_{cJ}}, \mathcal{B}_{\psi(3686)\to\gamma\chi_{cJ}}, \delta\mathcal{B}_{\psi(3686)\to\gamma\chi_{cJ}}) \\
&\times \mathcal{G}(N^{\rm nominal}_{\psi(3686),\rm I}, N_{\psi(3686),\rm I}, \delta N_{\psi(3686),\rm I}) \\
&\times \mathcal{G}(N^{\rm nominal}_{\psi(3686),\rm II}, N_{\psi(3686),\rm II}, \delta N_{\psi(3686),\rm II}) \\
&\times \mathcal{G}(\epsilon^{\rm nominal}_{\rm I}, \epsilon_{\rm I}, \delta\epsilon_{\rm I}) \\
&\times \mathcal{G}(\epsilon^{\rm nominal}_{\rm II}, \epsilon_{\rm II}, \delta\epsilon_{\rm II}) \\
&\times \prod_i [\mathcal{P}(N^{\rm expected}_{{\rm bkg,I},i}, N_{{\rm bkg,I},i}/f_{{\rm I},i}) \\
&\quad \otimes \mathcal{G}(N^{\rm observed}_{{\rm bkg,I},i}, N^{\rm expected}_{{\rm bkg,I},i}, \delta N_{{\rm bkg,I},i})] \\
&\times \prod_i [\mathcal{P}(N^{\rm expected}_{{\rm bkg,II},i}, N_{{\rm bkg,II},i}/f_{{\rm II},i}) \\
&\quad \otimes \mathcal{G}(N^{\rm observed}_{{\rm bkg,II},i}, N^{\rm expected}_{{\rm bkg,II},i}, \delta N_{{\rm bkg,II},i})].
\end{aligned}
$$

- **The draft has given the result on full data and it is in CWR process**

Ongoing analysis: $J/\psi \to \mu\tau$

BAM-00919

- **Previous result:** $\mathcal{B}(J/\psi \to \mu\tau) < 2.0 \times 10^{-6}$ @ 90% C. L. on BESII
- Plan to use $\mathbf{10084.3 \times 10^6}$ $\boldsymbol{J/\psi}$ **events** to search for $\boldsymbol{J/\psi \to \mu\tau,\ \tau \to e\nu_e\nu_\tau}$
- Detecting efficiency of signal decay is $16.83 \pm 0.01\%$
- Didn't give the upper limit result of semi-blind data yet
- Replying to the referees' first round of comments

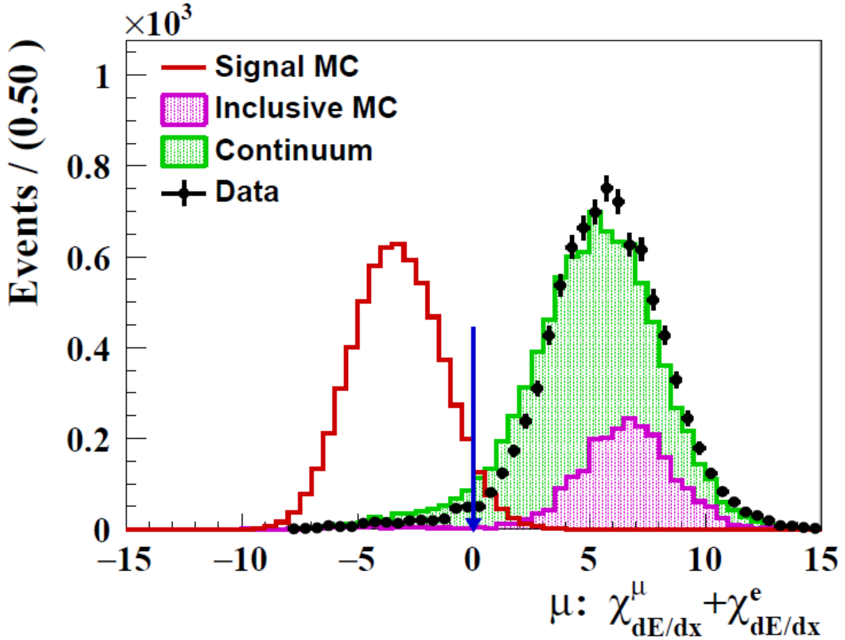


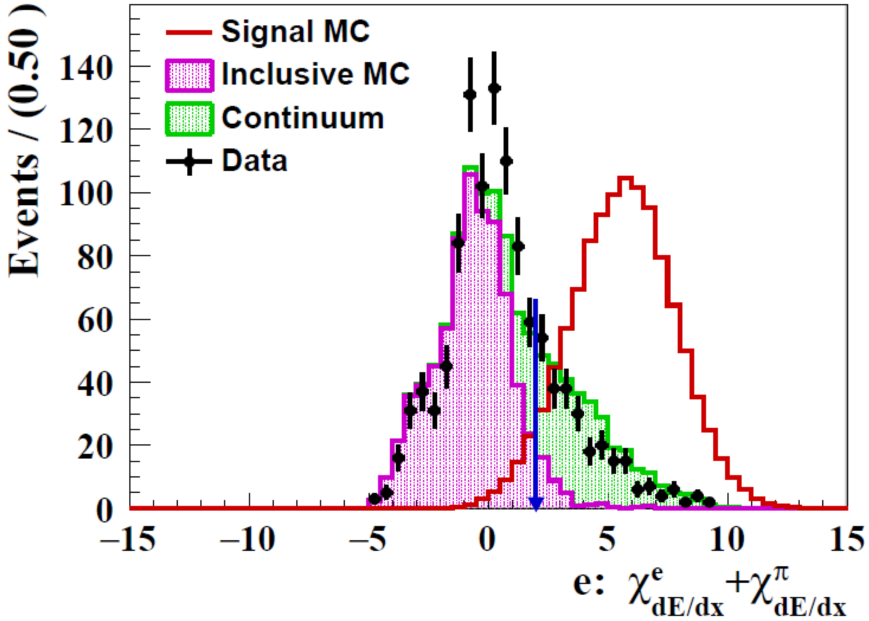
The surviving background events in the signal box from the **cocktail MC sample (not semi-blind data)**

Ongoing analysis: $\eta' \to e\mu$

BAM-00948

- **Search for $\eta' \to e\mu$ via $J/\psi \to \gamma\eta'$ with 10084.3×10^6 J/ψ events**
- **Previous result:** $\mathcal{B}(\eta' \to e\mu) < 4.7 \times 10^{-4}$ @ 90% C. L. (from CLEO, 2000)





- **It's hopeful to suppress the upper limit by 2~3 orders of magnitude.**

$$\mathcal{L}(\mathcal{B}, \varepsilon, N_{\eta'}, N_{\text{bkg1}}, N_{\text{bkg2}}) = \mathcal{P}\left(N_{\text{obs}} \mid N_{\eta'} \cdot \mathcal{B} \cdot \varepsilon + N_{\text{bkg1}} + N_{\text{bkg2}}\right) \cdot \mathcal{P}\left(N^{\text{inc}}_{\text{bkg1}} \middle| N_{\text{bkg1}}\right) \cdot \prod_i \mathcal{P}\left(N^i_{\text{bkg2}} \middle| N_{\text{bkg2}}/f_i\right) \cdot \mathcal{G}(\varepsilon \mid \varepsilon_{\text{MC}}, \varepsilon_{\text{MC}} \cdot \sigma_\varepsilon) \cdot \mathcal{G}\left(N_{\eta'} \middle| N^{\text{data}}_{\eta'}, N^{\text{data}}_{\eta'} \cdot \sigma_{N_{\eta'}}\right)$$

- Just updated the memo with full data.

Ongoing analysis

- **τ-related J/ψ two-body CLFV decay with leptonic decay tag of τ is ongoing**
  - $J/\psi \to e\tau, \tau \to \mu\nu_\mu\nu_\tau$
  - $J/\psi \to \mu\tau, \tau \to e\nu_e\nu_\tau$
  - Expected sensitivity: $\mathcal{O}(10^{-8})$
- **CLFV decays of $\psi(3686)$**
  - $\psi(3686) \to e\tau$
    - Events selection and background analysis
    - Expected sensitivity: $\mathcal{O}(10^{-8})$
- **CLFV decays of different quarkonium state**
  - States with different quantum numbers sensitive to different operators in EFT
  - 0^-: η', $\eta_c(1S)$
  - J^+: χ_{cJ}, $h_c(1P)$
  - Expected Sensitivity: $\mathcal{O}(10^{-8}\sim10^{-6})$

	$e\mu$	$e\tau$	$\mu\tau$	$\gamma e\mu$	$\gamma e\tau$	$\gamma\mu\tau$	N	sensitivity
η'	17.8 %	–	–	7.3 %	–	–	5×10^7	10^{-7}
$\eta_c(1S)$	26.0 %	17.7 %	20.7 %	16.9 %	12.4 %	12.1 %	2×10^8	10^{-8}
χ_{c0}	23.5 %	17.3 %	21.1 %	17.6 %	12.4 %	14.9 %	3×10^8	10^{-8}
χ_{c1}	26.0 %	19.1 %	22.0 %	18.1 %	14.3 %	16.7 %	3×10^8	10^{-8}
χ_{c2}	26.4 %	18.3 %	21.7 %	17.6 %	14.2 %	15.8 %	3×10^8	10^{-8}
$h_c(1P)$	15.8 %	11.3 %	13.4 %	11.1 %	8.6 %	10.0 %	2×10^6	10^{-6}

Efficiency of different decay from signal MC;
$N = eff \cdot \mathcal{B} \cdot N_\psi$,
N is calculated with $10B$ J/ψ and $3B$ $\psi(2S)$.

Summary

Summary

- Searching for CLFV process is a good probe for new physics.
- BESIII have measured the upper limit of branching fraction of $J/\psi \to e\mu, J/\psi \to e\tau$, and $\psi(3686) \to e\mu$.
  - $\boldsymbol{B(J/\psi \to e\mu) < 4.5 \times 10^{-9}}$ **@ 90% C. L.**
  - $\boldsymbol{B(J/\psi \to e\tau) < 7.5 \times 10^{-8}}$ **@ 90% C. L.**
  - $\boldsymbol{B(\psi(3686) \to e\mu) < 1.4 \times 10^{-8}}$ **@ 90% C. L.**
- More CLFV decay searching analyses at BESIII are ongoing.

Thanks for listening!

Back up

CLFV experimental research

Experimental searches in leptons (μ, τ), pseudoscalar mesons (K, π, B), vector mesons $(\phi, J/\psi, \Upsilon)$ and bosons (Z, H^0)

CLFV searches in muon

Decay model	Experiment	Upper limit (confidence level)
$\mu^+ \to e^+\gamma$	MEG	$4.2 \times 10^{-13}(90\%\ \mathrm{C.L.})$
$\mu^+ \to e^+e^-e^+$	SINDRUM	$1.0 \times 10^{-12}(90\%\ \mathrm{C.L.})$
$\mu^- N \to e^- N$	SINDRUM-II	$6.1(7.1) \times 10^{-13} Ti(Au)(90\%\ \mathrm{C.L.})$
$\mu^- N \to e^- N'$	SINDRUM-II	$5.7 \times 10^{-13}(90\%\ \mathrm{C.L.})$

CLFV experimental research

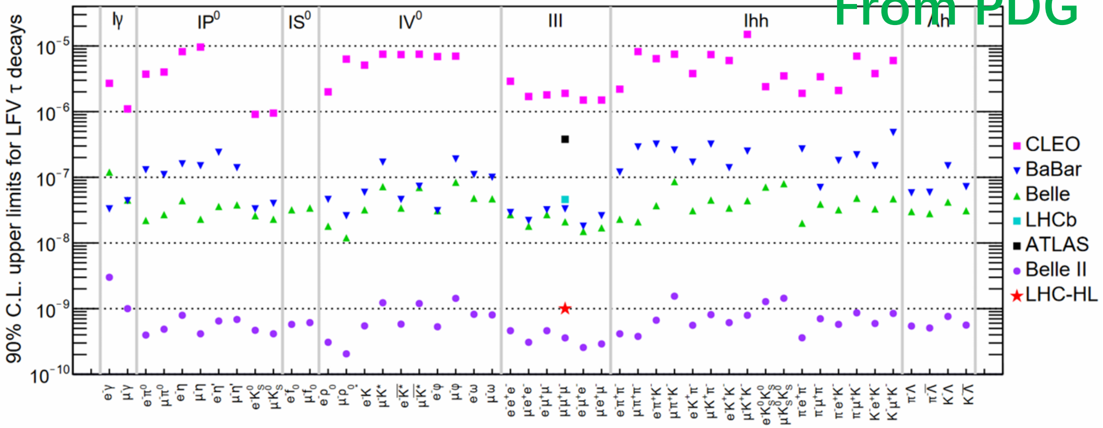
Experimental searches in leptons (μ, τ), pseudoscalar mesons (K, π, B), vector mesons $(\phi, J/\psi, \Upsilon)$ and bosons (Z, H^0)

CLFV searches in τ

Decay model	Experiment	Upper limit (confidence level)
$\tau^{\pm} \to e^{\pm}\gamma$	BaBar	$3.3 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau^{\pm} \to \mu^{\pm}\gamma$	BaBar	$4.4 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau \to eee$	Belle	$2.7 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau \to \mu\mu\mu$	Belle	$2.1 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau \to \mu ee$	Belle	$1.8 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau \to e\mu\mu$	Belle	$2.7 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau \to \pi^0 e$	Belle	$8.0 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau \to \pi^0 \mu$	BaBar	$1.1 \times 10^{-7}(90\%\ \mathrm{C.L.})$
$\tau \to \eta e$	Belle	$9.2 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau \to \eta\mu$	Belle	$6.5 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau \to \rho^0 e$	Belle	$1.8 \times 10^{-8}(90\%\ \mathrm{C.L.})$
$\tau \to \rho^0 \mu$	Belle	$1.2 \times 10^{-8}(90\%\ \mathrm{C.L.})$

$$\mathcal{O}(10^{-7} \sim 10^{-8})$$

From PDG



CLFV experimental research

Experimental searches in leptons (μ,τ), pseudoscalar mesons (K,π,B), vector mesons $(\phi,J/\psi,\Upsilon)$ and bosons (Z,H^0)

CLFV searches in pseudoscalar mesons (K,π,B)

Decay model	Experiment	Upper limit (confidence level)
$\pi^0 \to e\mu$	KTeV	$3.6\times10^{-10}(90\%\ \mathrm{C.L.})$
$K_L^0 \to \pi^0\mu^+e^-$	KTeV	$7.6\times10^{-11}(90\%\ \mathrm{C.L.})$
$K_L^0 \to e\mu$	BNL E871	$4.7\times10^{-12}(90\%\ \mathrm{C.L.})$
$K^+ \to \pi^+\mu^+e^-$	BNL E865	$1.3\times10^{-11}(90\%\ \mathrm{C.L.})$
$B^0 \to \mu e$	LHCb	$2.8\times10^{-9}(95\%\ \mathrm{C.L.})$
$B^0 \to \tau e$	BaBar	$2.8\times10^{-5}(90\%\ \mathrm{C.L.})$
$B^0 \to \tau\mu$	LHCb	$1.4\times10^{-5}(95\%\ \mathrm{C.L.})$
$B \to K\mu e$	BaBar	$3.8\times10^{-8}(90\%\ \mathrm{C.L.})$
$B \to K^*\mu e$	BaBar	$5.1\times10^{-7}(90\%\ \mathrm{C.L.})$
$B^+ \to K^+\tau e$	BaBar	$4.8\times10^{-5}(90\%\ \mathrm{C.L.})$
$B^+ \to K^+\tau\mu$	BaBar	$3.0\times10^{-5}(90\%\ \mathrm{C.L.})$
$B_s^0 \to \mu e$	LHCb	$1.1\times10^{-8}(90\%\ \mathrm{C.L.})$
$B_s^0 \to \tau\mu$	LHCb	$4.2\times10^{-5}(95\%\ \mathrm{C.L.})$

CLFV searches in vector mesons $(\phi,J/\psi,\Upsilon)$

Decay model	Experiment	Upper limit (confidence level)
$\phi \to e^\pm\mu^\mp$	SND	$2\times10^{-6}(90\%\ \mathrm{C.L.})$
$\Upsilon(1S) \to \mu^\pm\tau^\mp$	CLEO	$6.0\times10^{-6}(95\%\ \mathrm{C.L.})$
$\Upsilon(2S) \to \mu^\pm\tau^\mp$	CLEO	$14.4\times10^{-6}(95\%\ \mathrm{C.L.})$
$\Upsilon(3S) \to \mu^\pm\tau^\mp$	CLEO	$20.3\times10^{-6}(95\%\ \mathrm{C.L.})$
$\Upsilon(3S) \to e^\pm\mu^\mp$	BaBar	$3.6\times10^{-7}(90\%\ \mathrm{C.L.})$
$\Upsilon(1S) \to e^\pm\mu^\mp$	Belle	$3.6\times10^{-7}(90\%\ \mathrm{C.L.})$
$\Upsilon(1S) \to \mu^\pm\tau^\mp$	Belle	$2.6\times10^{-6}(90\%\ \mathrm{C.L.})$
$\Upsilon(1S) \to e^\pm\tau^\mp$	Belle	$2.4\times10^{-6}(90\%\ \mathrm{C.L.})$
$J/\psi \to \mu e$	BESIII	$4.5\times10^{-9}(90\%\ \mathrm{C.L.})$
$J/\psi \to \tau e$	BESIII	$7.5\times10^{-8}(90\%\ \mathrm{C.L.})$
$J/\psi \to \tau\mu$	BESII	$2.0\times10^{-6}(90\%\ \mathrm{C.L.})$

CLFV searches in bosons (Z^0,H)

Decay model	Experiment	Upper limit (confidence level)
$Z^0 \to e^\pm\mu^\mp$	ATLAS	$7.5\times10^{-7}(95\%\ \mathrm{C.L.})$
$Z^0 \to e^\pm\tau^\mp$	OPAL	$9.8\times10^{-6}(95\%\ \mathrm{C.L.})$
$Z^0 \to \mu^\pm\tau^\mp$	DELPHI	$1.2\times10^{-5}(95\%\ \mathrm{C.L.})$
$H \to e^\pm\mu^\mp$	ATLAS	$6.1\times10^{-5}(95\%\ \mathrm{C.L.})$
$H \to e^\pm\tau^\mp$	CMS	$2.2\times10^{-3}(95\%\ \mathrm{C.L.})$
$H \to \mu^\pm\tau^\mp$	CMS	$1.5\times10^{-3}(95\%\ \mathrm{C.L.})$

Systematic uncertainty of $J/\psi \to e\mu$

Four major systematic uncertainty sources

- Tracking and PID efficiency
  - Control sample: $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$
  - tracking: 0.05% for electron and muon
  - PID: 3.9% for electron, 10% for muon
  - Combined: 13%
- TOF timing
  - Control sample: $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$
  - Relative difference of MC and data: 0.48% for electron, 0.19% for muon
  - Sum in quadrature: 0.52%
- Photon veto
  - Control sample: $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$
  - Relative difference of MC and data: 0.83% for electron, 0.59% for muon
  - Systematic uncertainty: 0.83%
- $|\Delta\theta|$ and $|\Delta\phi|$ requirements
  - Control sample: $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$
  - Relative difference of MC and data: 2.6% for electron, 2.4% for muon
  - Systematic uncertainty: 2.6%

Sources	Systematic uncertainty
Tracking and PID efficiency	13%
TOF timing	0.52%
Photon veto	0.83%
$|\Delta\theta|$ and $|\Delta\phi|$ requirements	2.6%
Total	**14%**

Systematic uncertainty of $J/\psi \to e\tau$

- Number of J/ψ
- Quoted BF of $\tau^+ \to \pi^-\pi^0\nu_\tau$
- signal MC model
  - TAUVECTORNU
  - VSS
  - 0.6% for sample I, negligible for sample II
- pion PID
  - A study of control sample of $J/\psi \to \rho\pi$
- pion tracking
  - using control sample of $J/\psi \to \pi^+\pi^- p\bar{p}$
  - difference between data and MC is 1.0%
- PID and tracking efficiencies of electrons
  - $e^+e^- \to \gamma e^+e^-$ control sample
  - PID: 0.4% for sample I, 0.9% for sample II
  - tracking: 0.1% for sample I, 0.1% for sample II
- photon detection efficiency
  - control sample: $J/\psi \to \pi^+\pi^-\pi^0, \pi^0 \to \gamma\gamma$
  - barrel region: 0.5%; end cap region: 1.5%
  - average: 0.5% per photon
  - Total systematic uncertainty: 1.0%
- π^0 reconstruction
  - Study based on $J/\psi \to \pi^+\pi^-\pi^0$ control sample
  - Taken as 1.0%
- P_e and M_{e_recoil} requirements
  - control sample of process $e^+e^- \to \gamma e^+e^-$
  - 3.0%(3.3%) for sample I(II)
- E_{miss} requirement
  - Control sample: $e^+e^- \to \gamma e^+e^-$
  - 1.0% (0.8%) for sample I(II)

Sources	Sample I	Sample II
Number of J/ψ	0.5%	0.4%
Quoted BF*	0.4%	0.4%
MC model	0.6%	…
Pion PID*	1.0%	1.0%
Pion tracking*	1.0%	1.0%
Electron PID	0.4%	0.9%
Electron tracking*	0.1%	0.1%
Photon detection*	1.0%	1.0%
π^0 reconstruction*	1.0%	1.0%
P_e and M_{e_recoil} requirements	3.0%	3.3%
E_miss requirement	1.0%	0.8%
Total uncertainty	3.9%	4.1%