The 19th International Conference on Hadron Spectroscopy and Structure

Charged LFV searching in J/ψ decays at BESIII

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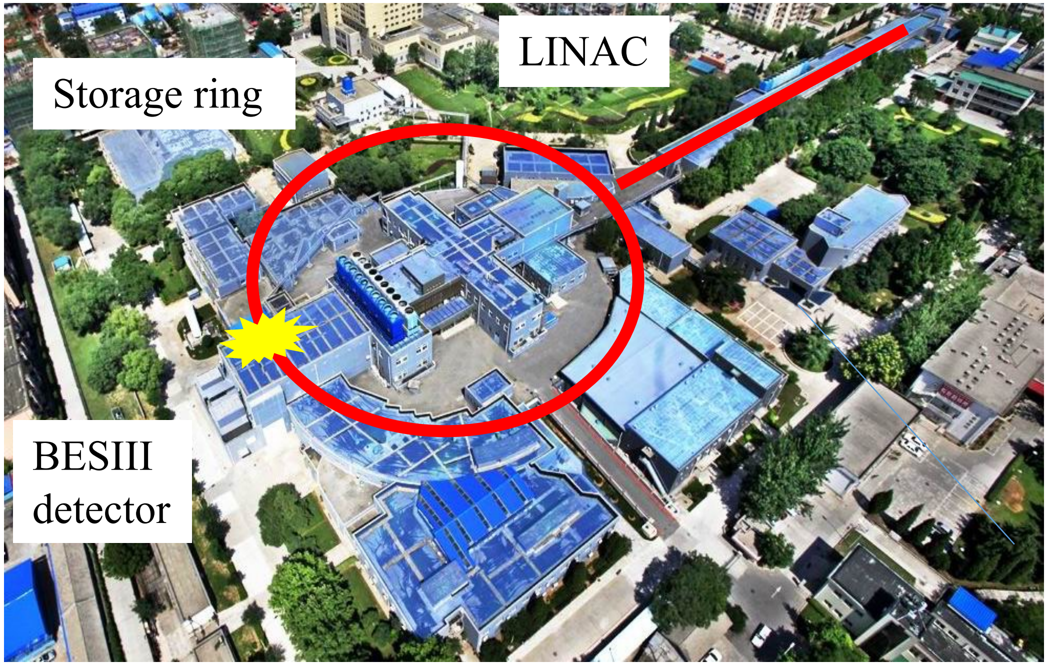
Outline

- **Introduction of BEPCII/BESIII**
- **Charged lepton flavor violation in J/ψ decays**
  - **Search for $J/\psi \to e^{\pm}\tau^{\mp}, \tau^{\mp} \to \pi^{\mp}\pi^{0}\nu_{\tau}$**
  - **Search for $J/\psi \to e^{\pm}\mu^{\mp}$**
- **Prospect**
- **Summary**

BEPCII AND BESIII

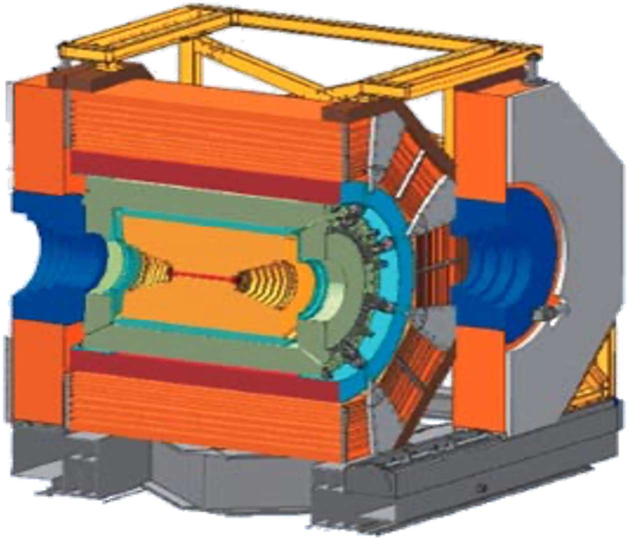


BEPCII:

•First collision in 2008, physics run in 2009

•Energy region: 2.0 – 4.95 GeV

•Designed luminosity: $1 \times 10^{33}\ cm^{-2}s^{-1}$ @ ψ(3770), reach in April 2016



MDC

- small cell & Gas, He/C_3H_8 (60/40)
- σ_{xy} = 120 μm
- σ_p/p = 0.5% @ 1 GeV/c
- dE/dx = 6%

TOF

- σ_t = 80 ps (Barrel)
  60 ps(Endcap)

EMC:

- CsI(Tl)
- ΔE/E = 2.5% @ 1 GeV
- σ_z=0.6 cm

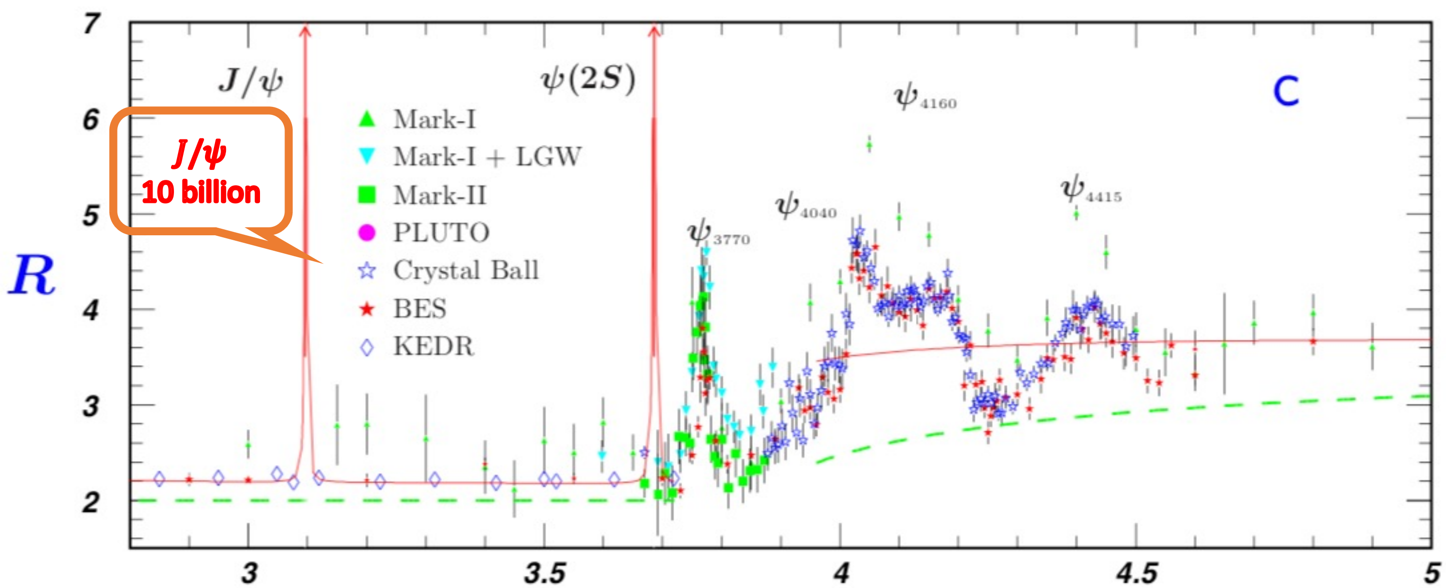
MUC

- 9 layers RPC for barrel
- 8 layers RPC for endcap

Superconducting magnet (1T)

With the world largest data sample on J/ψ and $\psi(2S)$, unique data sample at 3.773, 4.008, 4.226 …GeV, BESIII have great potential in new physics

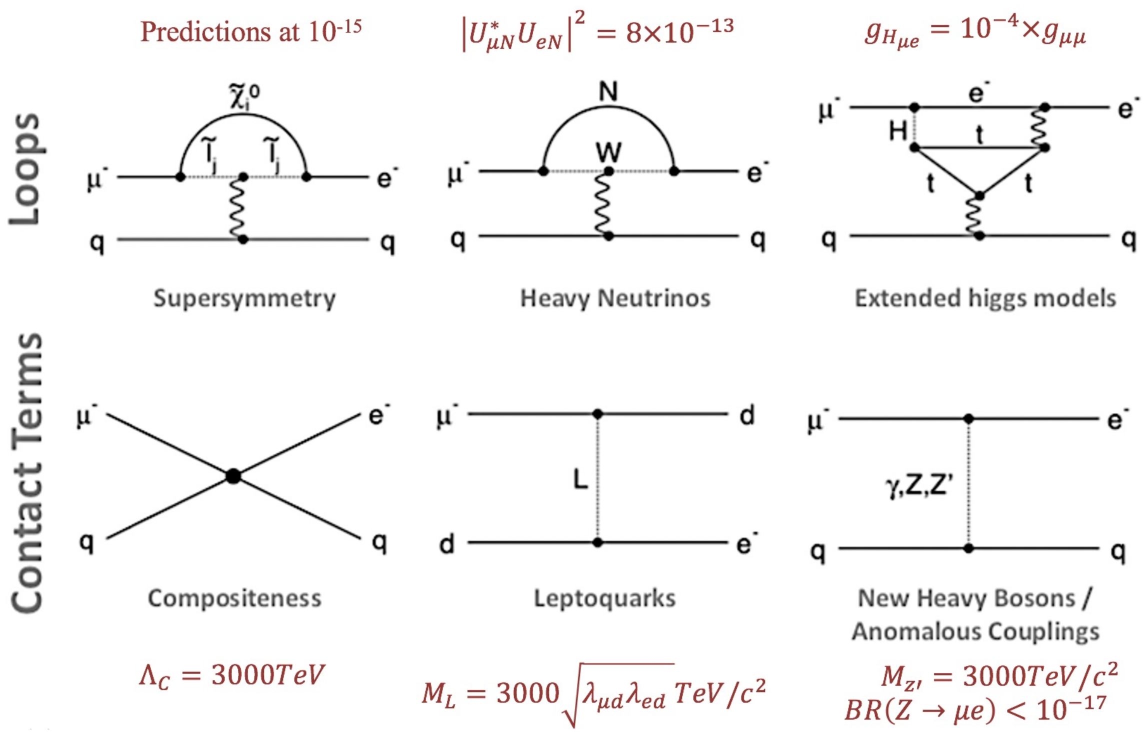
- Charged lepton flavor (number) violation (CLFV/LNV) decays
- Baryon number violation (BNV) decays
- Rare decays of charmonia and charmed hadrons
- Searches for light (invisible) new particles
- Off-resonance searches



For further information, see "Future Physics Programme of BESIII" Chin. Phys. C 44, 040001 (2020).

Charged lepton flavor violation

- In the Standard Model (SM) of particle physics, the LFV process is forbidden. However, flavor nonconserving mixing among generations has been observed in neutrino oscillations.
- The smallness of neutrino masses leads to a very large suppression of the predicted branching fractions [1]. So, any significant sign of a CLFV signal could indicate physics beyond the SM.

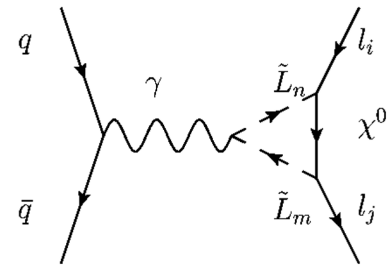


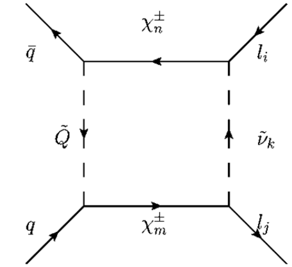
James Miller, 2006

[1] L. Calibbi et al. Riv. Nuovo Cimento 41, 71 (2018).

J/ψ CLFV studies

- New physics models predicting BR($J/\psi \rightarrow e\mu$) to 10^{-16}~10^{-9}, BR($J/\psi \rightarrow e\tau(\mu\tau)$) to 10^{-10}~10^{-8}.
  - model-independent prediction [1, 2]
  - rotating mass matrix [3]
  - unparticle physics [4]
  - effective Lagrangian [5]
  - MSSM with gauged baryon and lepton number [6]
  - …





- Experimental results

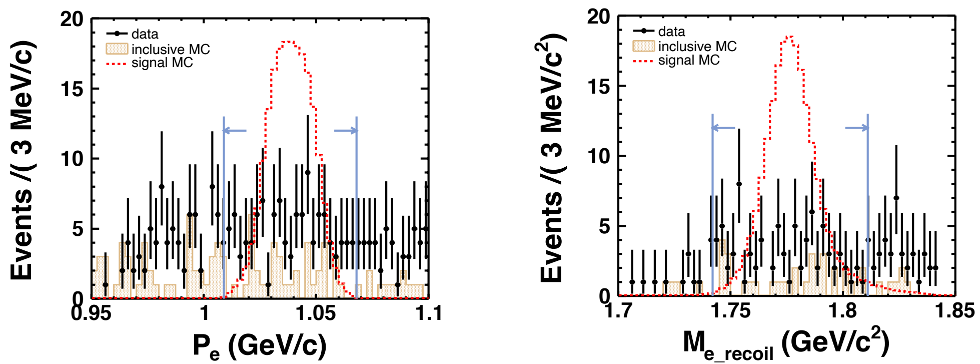
	J/ψ number	$J/\psi \rightarrow e\mu$	$J/\psi \rightarrow e\tau$	$J/\psi \rightarrow \mu\tau$
BES	58 million	$< 1.1\times10^{-6}$ [7]	$< 8.3\times10^{-6}$ [8]	$< 2.0\times10^{-6}$ [8]
BESIII	225 million	$< 1.6\times10^{-7}$ [9]	-	-

[1] X. M. Zhang et al, Phys. Rev. D 63, 016003 (2000).
[2] T. Gutche et al, Phys. Rev. D 83, 115015 (2011).
[3] J. Bordes and H. M. Chan, Phys. Rev. D 63, 016006 (2000).
[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).
[7] J. Z. Bai et al. (BES Collaboration), Phys. Lett. B 561, 112007 (2003).
[8] M. Ablikim et al. (BES Collaboration), Phys. Lett. B 598, 172 (2004).
[9] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. D 87, 112007 (2013).

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

Phys. Rev. D 103, 112007 (2021)

- Based on 10 billion J/ψ data set:
  1310.6M collected @2009+2012 (sample I)
  8774.01M collected @2017-2019 (sample II)
- $J/\psi \to e\tau$, $\tau \to \pi\pi^0\nu$.
  - Select one electron and one charged pion.
  - At least two photon showers and one π^0.
  - Two-body-decay:



  - One undetected neutrino with missing energy $E_{miss} > 0.43GeV$.

- Blind analysis to avoid possible bias.

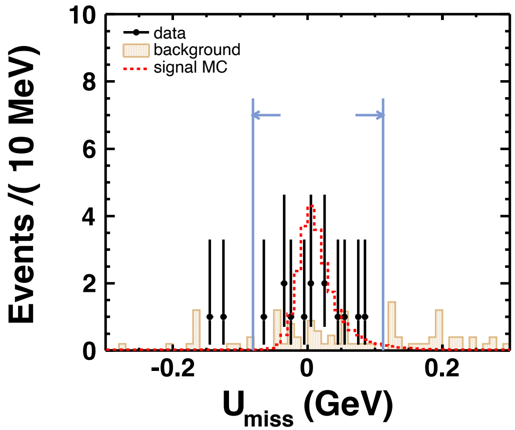
Search for $J/\psi \to e^{\pm}\tau^{\mp}$

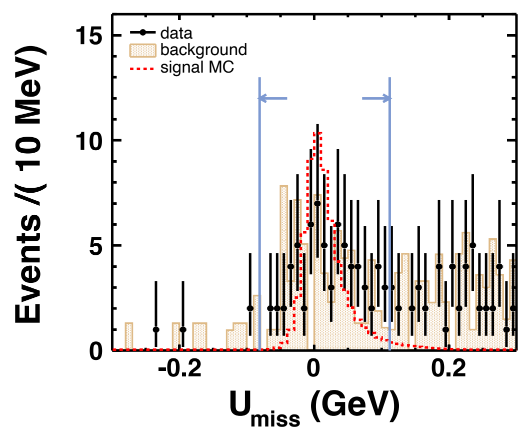
Phys. Rev. D 103, 112007 (2021)

- Background from J/ψ resonance and continuum process.

	$N_{bkg}^{J/\psi}$	$N_{bkg}^{cont.}$	N_{bkg}^{total}	N_{data}
Sample I	1.1 ± 0.8	5.8 ± 1.8	6.9 ± 1.9	13
Sample II	25.7 ± 6.4	37.9 ± 11.5	63.6 ± 13.2	69

- Total systematic uncertainty ~ 4%.
- No excess of events is observed over the background.



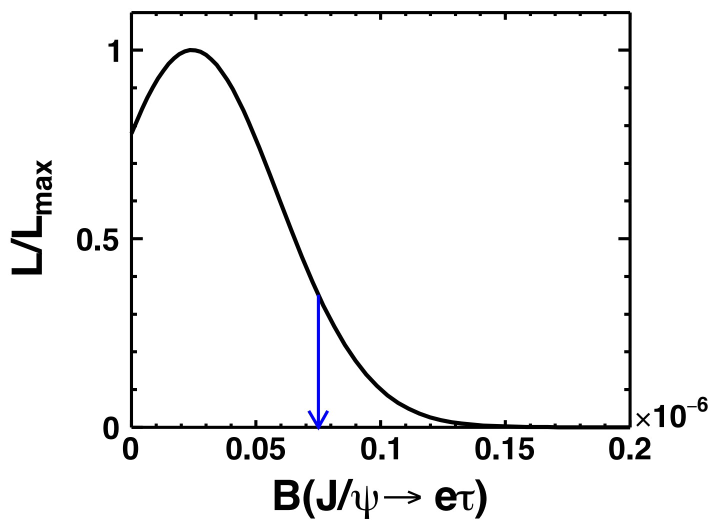


$$U_{miss} = E_{miss} - c|\vec{P}_{miss}|$$

Result for $J/\psi \to e^{\pm}\tau^{\mp}$

Phys. Rev. D 103, 112007 (2021)

- Determination of upper limit at 90% confidence level (C.L.) with Bayesian method, assume:
  - the survived data events ~ Poisson,
  - detection efficiency ~ Gaussian,
  - background estimation ~ Gaussian.
- Combined result:
  - $BR(J/\psi \to e\tau) < 7.5\times10^{-8}$ @ 90% C.L.
- This result improves the previous published limits by two orders of magnitude and comparable with the theoretical predictions.

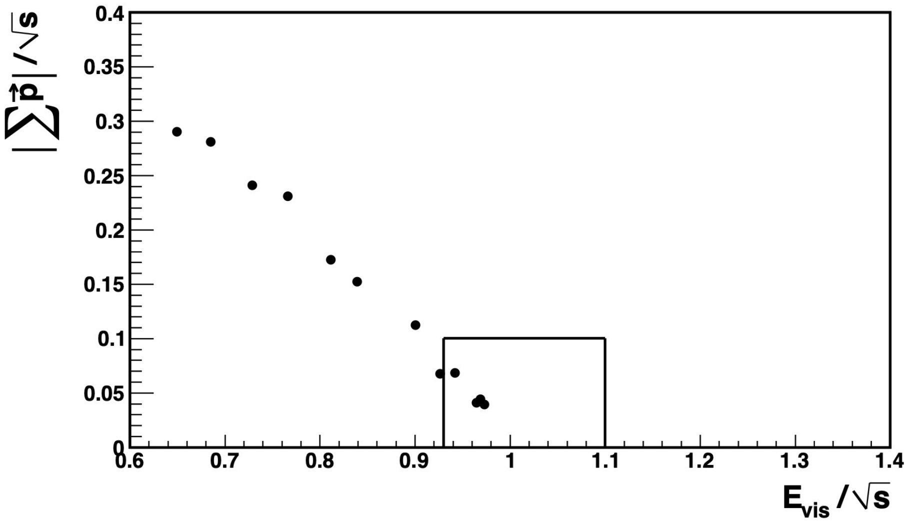


Result for $J/\psi \to e^{\pm}\mu^{\mp}$

Phys. Rev. D 87, 112007 (2013)

- Data set: 225 million J/ψ.
- Two opposite charged tracks, no missing track.
- 4 candidate events are found in the signal region, consistent with background expectations (4.75 ± 1.09).
- Total systematic uncertainty ~ 5.8%.
- Upper limit is obtained by the Feldman-Cousins method with systematic uncertainties included.
- Upper limit on branching ratio (90% C.L.)

$$BR(J/\psi \to e\mu) < 1.6\times10^{-7}$$



Update:

- Data set: 10 billion J/ψ.
- Upper limit prediction 10^{-9}~10^{-8}.

Prospect: More CLFV?

- $J/\psi \to e\tau,\ \tau \to \mu\nu_\mu\nu_\tau$ and $J/\psi \to \mu\tau,\ \tau \to e\nu_e\nu_\tau$
  - Two opposite charged tracks, two missing tracks.
  - Data set: 58 million → 10 billion.
  - Upper limit prediction 10^{-8}.

- $J/\psi \to \gamma e\tau$ and $J/\psi \to \gamma\mu\tau$
  - Two opposite charged tracks, one EMC shower, several missing tracks.
  - Data set: 10 billion.
  - No previous measurement.
  - Upper limit prediction 10^{-8}.

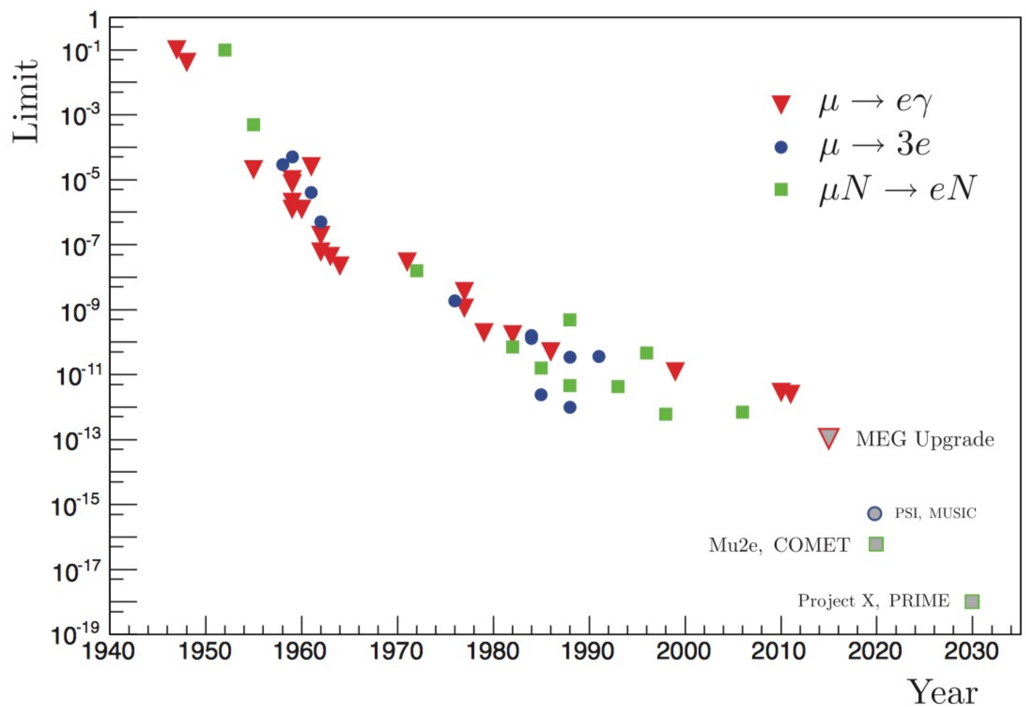
Summary

- BESIII collaboration searched for charged LFV with the world largest e^+e^- annihilation J/ψ:
  - $BR(J/\psi \to e\tau) < 7.5\times10^{-8}$ @ 90% C.L. (10 billion)
    Phys. Rev. D 103, 112007 (2021)
  - $BR(J/\psi \to e\mu) < 1.6\times10^{-7}$ @ 90% C.L. (225 million)
    Phys. Rev. D 87, 112007 (2013)
- Better results for more decay channels based on 10 billion J/ψ data are coming soon.
  - $J/\psi \to e\mu$
  - $J/\psi \to e\tau/\mu\tau$, with $\tau \to l\nu\nu_\tau$
  - $J/\psi \to \gamma l_1 \bar{l}_2$
- New data taking plan and more charmonium data sets at other center-of-mass energy have been approved! Better/more constraints on LFV processes can be expected.

Thanks !

Backup: current experimental status

Reaction	UL	Future sensitivity
$BR(\mu^+ \to e^+\gamma)$	$<4.2\times10^{-13}$	$\sim5\times10^{-14}$(PSI)
$BR(\mu^\pm \to e^\pm e^+ e^-)$	$<1.0\times10^{-12}$	$\sim1.0\times10^{-16}$(PSI)
$R(\mu^- N \to e^- N')$	$<7\times10^{-13}$ (N=Au)	$\sim10^{-17}$(Mu2e and COMET)



Channel	UL
$BR(\tau \to e\gamma)$	$<3.3\times10^{-8}$
$BR(\tau \to \mu\gamma)$	$<4.4\times10^{-8}$
$BR(\tau \to e\pi^0)$	$<8.0\times10^{-8}$
$BR(K_L^0 \to e^\pm\mu^\mp)$	$<4.7\times10^{-12}$
$BR(\pi^0 \to e^\pm\mu^\mp)$	$<3.6\times10^{-10}$
$BR(\phi \to e^\pm\mu^\mp)$	$<2.0\times10^{-6}$
$BR(\Upsilon(1S) \to \tau^\pm\mu^\mp)$	$<6.0\times10^{-6}$
$BR(\Upsilon(2S) \to \tau^\pm e^\mp)$	$<3.2\times10^{-6}$
$BR(\Upsilon(2S) \to \tau^\pm\mu^\mp)$	$<3.3\times10^{-6}$
$BR(H \to e^\pm\mu^\mp)$	$<3.5\times10^{-4}$
$BR(H \to e^\pm\tau^\mp)$	$<6.1\times10^{-3}$
$BR(H \to \mu^\pm\tau^\mp)$	$<2.5\times10^{-3}$

R. H. Bernstein & P. S. Cooper, Phys. Rept. 532 (2013) 27.

- Select two good charged tracks. The electron candidate passes the $CL(e) > CL(\pi,\text{K})$, $\frac{CL(e)}{CL(\pi)+CL(e)} > 0.95$ and E/p >0.8 requirement. The pion candidate passes the $CL(\pi) > CL(e,\text{K})$ requirement.
- Select at least two good showers.
- Select π^0 with $0.115<M_{\gamma\gamma}<0.150$ GeV and 1C kinematic fit with $\chi^2<200$.
- Two-body-decay:
  - $1.009GeV < P_e < 1.068\ GeV$ and $1.742GeV < M_{e\_recoil} < 1.811\ GeV$.
- Missing energy $E_{miss} > 0.43GeV$.

Backup: Systematic uncertainty for $J/\psi \rightarrow e^{\pm}\tau^{\mp}$

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%