# Search for charged lepton flavor violation at BESIII

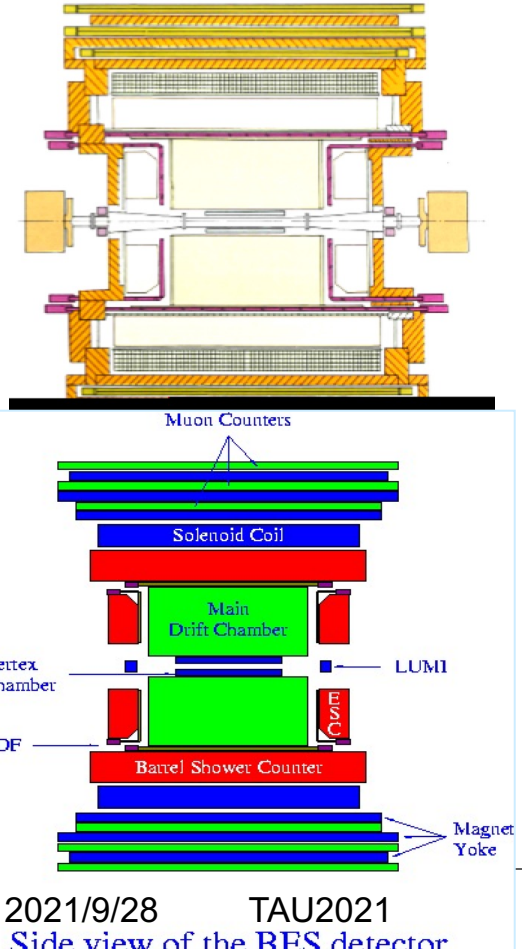

Dayong Wang

dayong.wang@pku.edu.cn

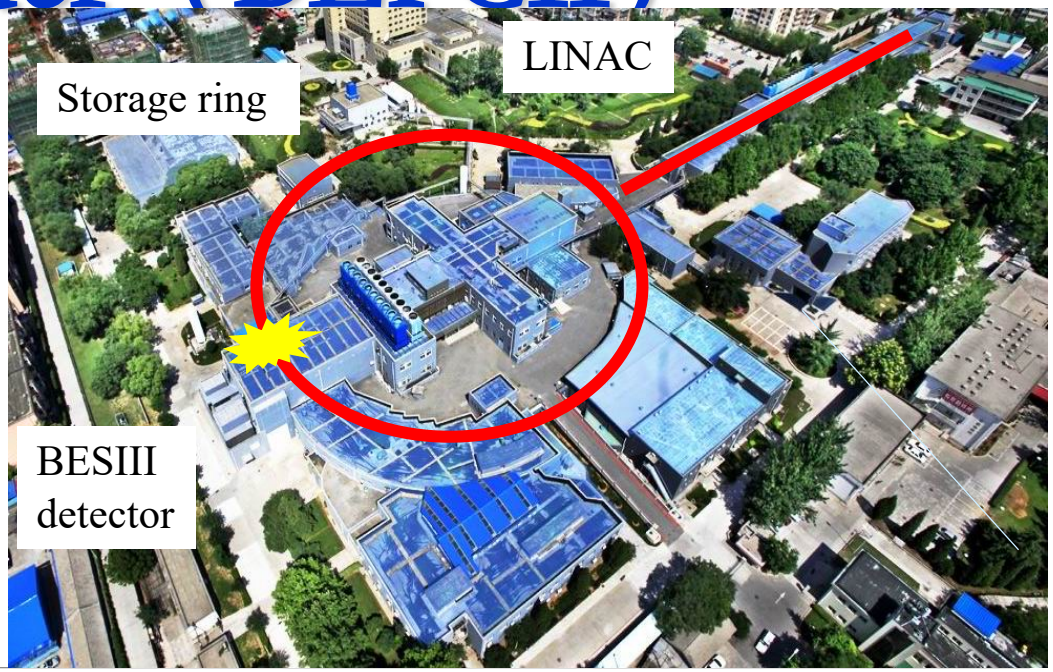
北京大学 PEKING UNIVERSITY

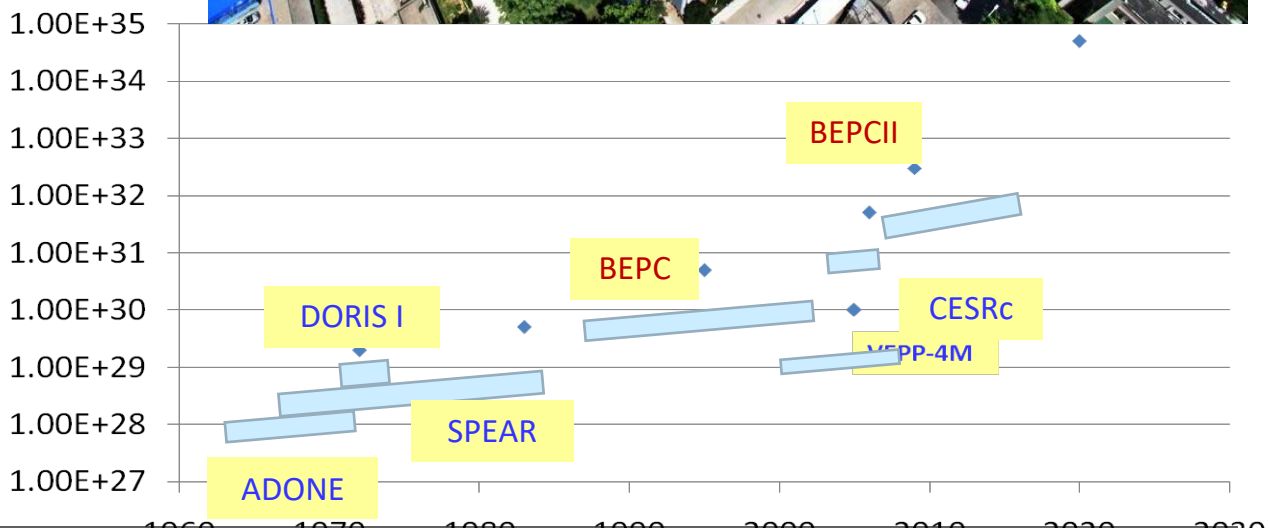

# Beijing Electron Positron Collider (BEPCII)

- 1984 ground breaking
- 1988 1st collision
- 1989 data-taking began
- Minor updates in mid-90s



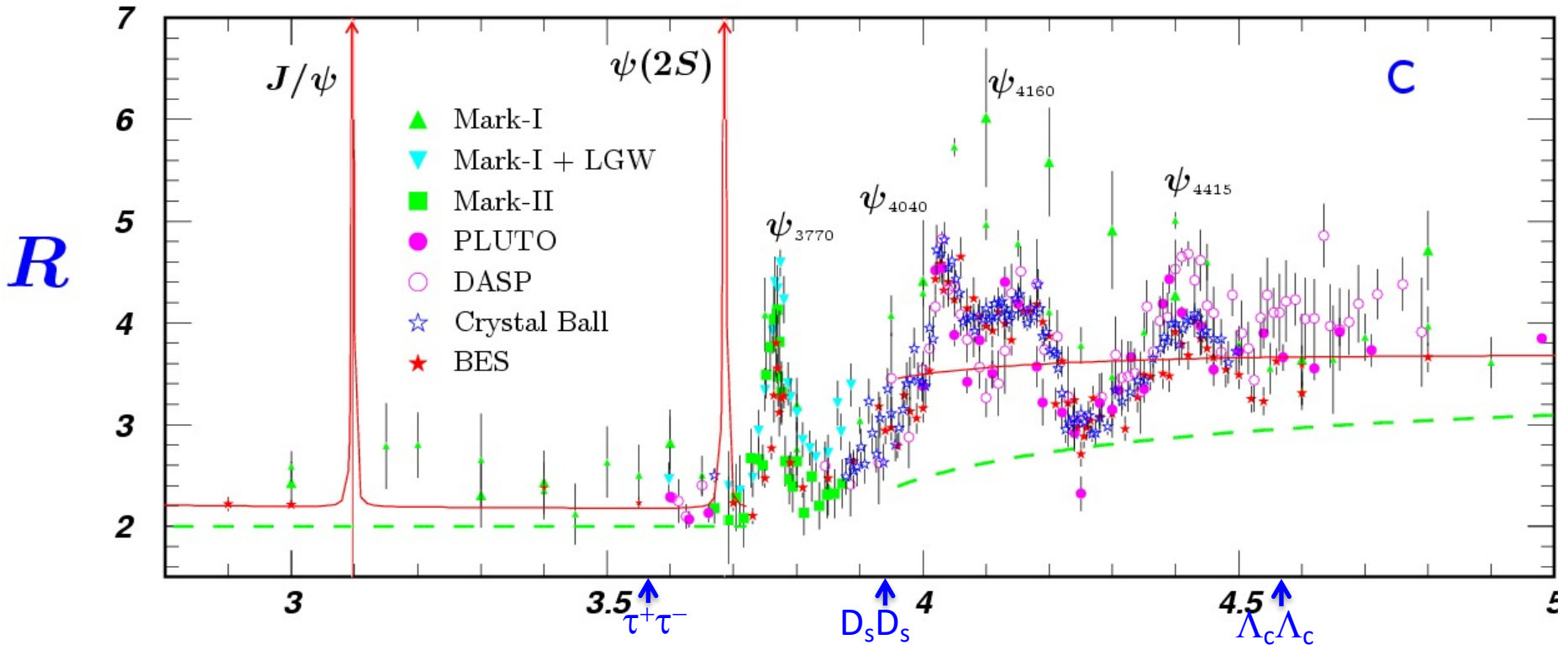

Side view of the BES detector



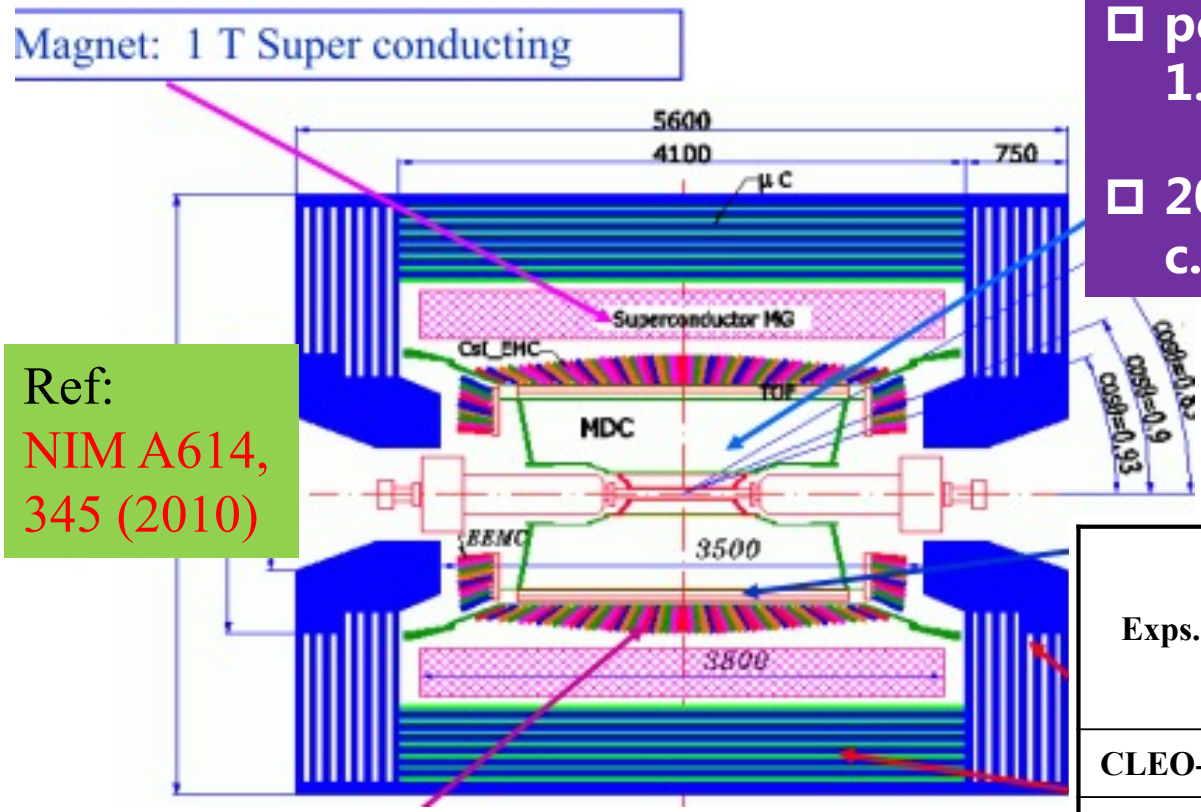



# BEPCII: a τ-c Factory

- Rich of **resonances**, charmonia and charmed mesons.
- **Threshold** characteristics (pairs of τ, D, $D_s$, charmed baryons…).
- **Transition** between perturbative and non-perturbative **QCD**.
- New hadrons: glueballs, hybrids, multi-quark states
- **Rare** and **forbidden** decays: **New Physics** beyond the SM



# BESIII experiment@BEPCII




Ref:
NIM A614, 345 (2010)

- peak lumi of $1x10^{33}$ $cm^{-2}s^{-1}$ at 1.89GeV reached in April 2016
- 2019-2021: top-up injection , c.m.s. E=>4.94GeV

| Exps. | MDC Spatial resolution | MDC dE/dx resolution | EMC Energy resolution |
|---|---|---|---|
| CLEO-c | 110 μm | 5% | 2.2-2.4 % |
| BaBar | 125 μm | 7% | 2.67 % |
| Belle | 130 μm | 5.6% | 2.2 % |
| BESIII | 115 μm | <5% (Bhabha) | 2.4% |

Clean environment, high luminosity, large acceptance and high efficiency at BESIII are helpful for indirect probe of new physics

# BESIII data samples

~ 3 B $\psi(3686)$ events ~ 140×CLEO-c

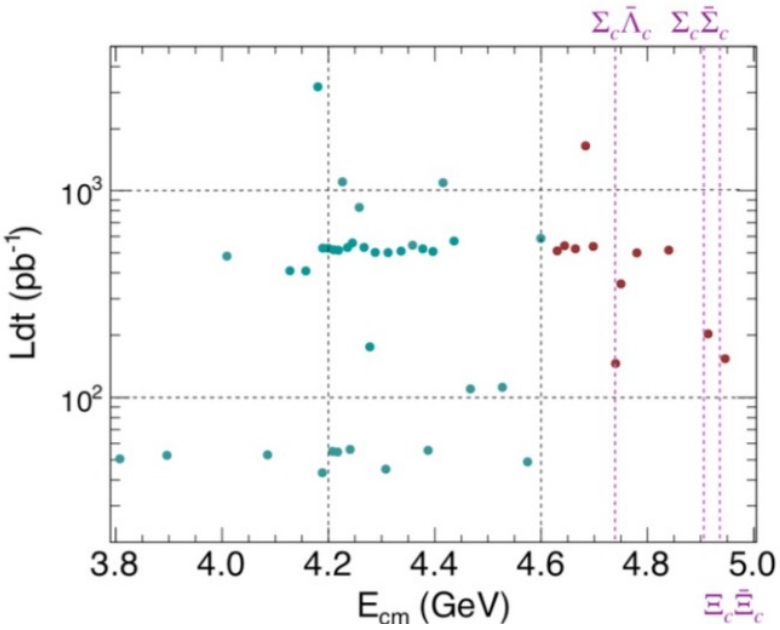
~ 10 B $J/\psi$ events ~ 170×BESII

~ 2.9/fb (20/fb soon) $\psi(3770)$ ~ 3.5(24)×CLEO-c

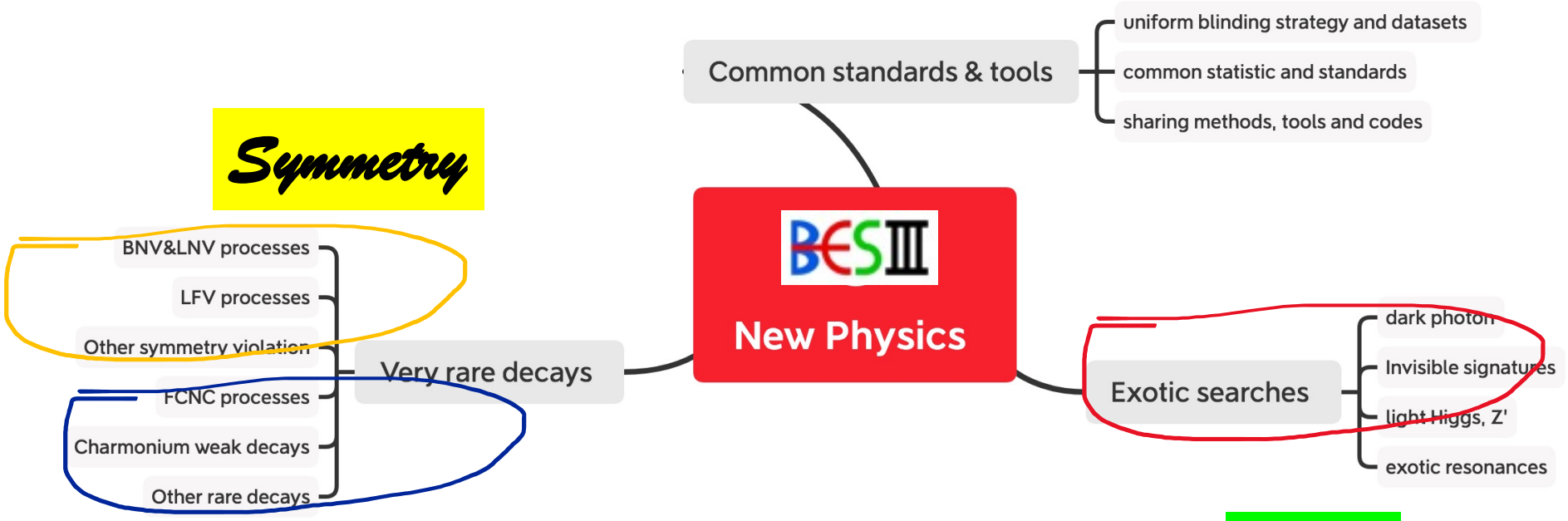
~23/fb (30+15/fb in future) **XYZ** above 4 GeV Unique

- 20 points for R &QCD Scan: 500/pb in 2015
- Y(2175) resonance: 100 /pb :
- 3/fb Ds data at 4170 MeV ~ 5×CLEO-c
- 3.8/fb 4.6-4.7GeV data in 2020
- 4.7-4.95GeV in 2021

~ other data sets: tau, $\Lambda_c$, resonance scan and continuum, etc.



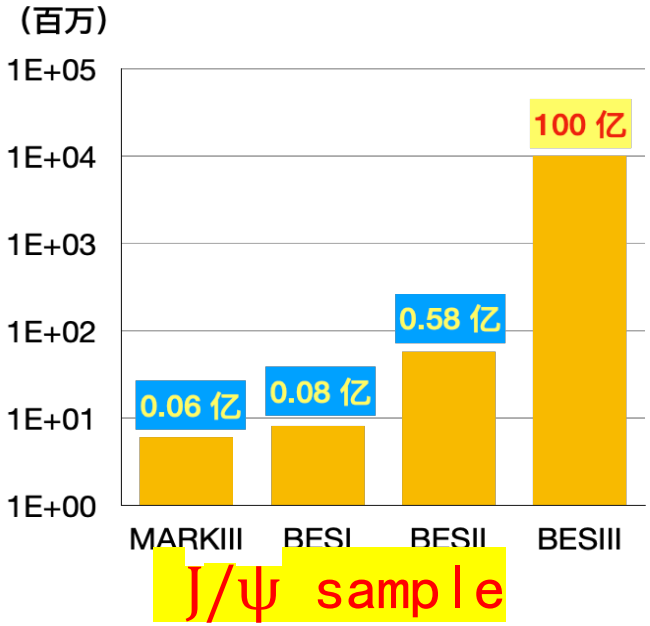
# BESIII New Physics Program



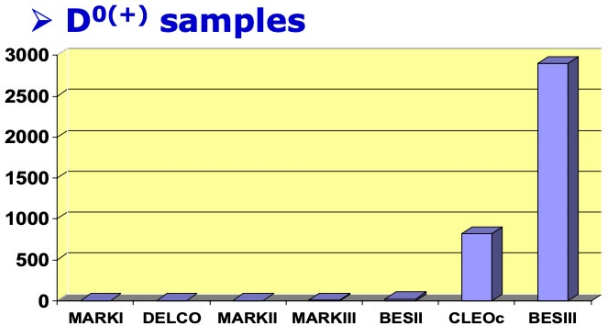

**More details, r.f.**

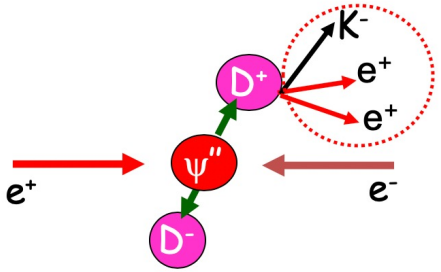
- ✓ New Physics Searches at the BESIII Experiment, Shenjian Chen and Stephen Olsen, NSR, arXiv:2102.13290
- ✓ New Physics Program of BES, Dayong Wang, in 《30 Years of BES Physics》

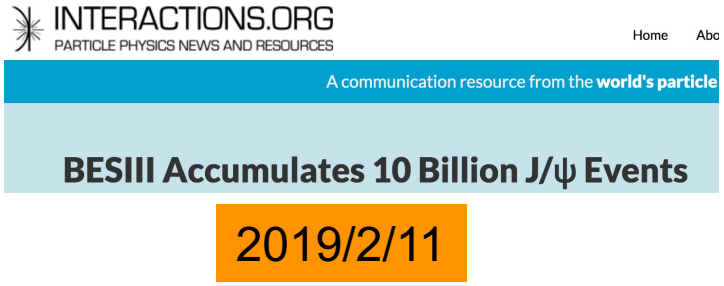
# Features for NP search@BESIII

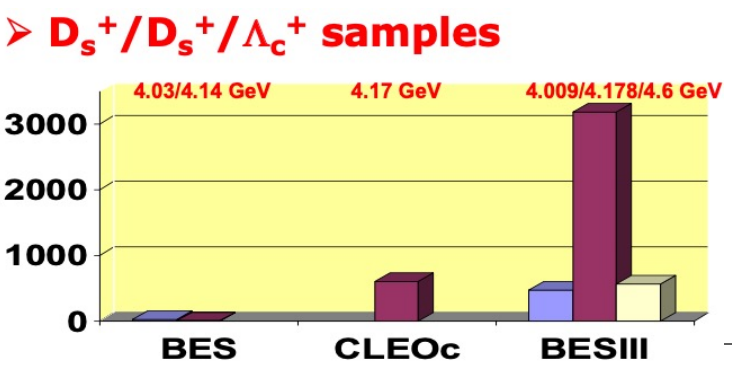


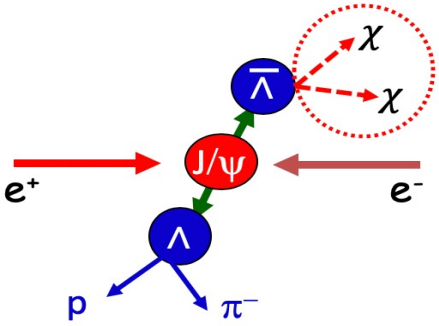

- Event is very clean
- High tagging efficiency
- Many systematic uncertainties can be cancelled
- Could measure absolute BFs



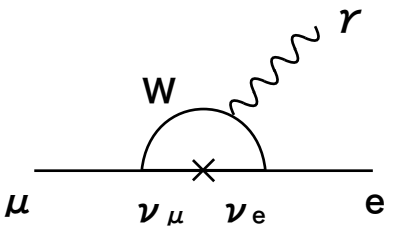



# charged lepton flavor violation(cLFV)

Considering neutrino mixing, extended νSM

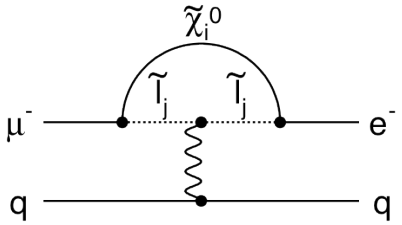



$$\mathcal{M} \propto \sum_j U_{ej} U^*_{\mu j} \frac{m_j^2}{M_W^2}$$

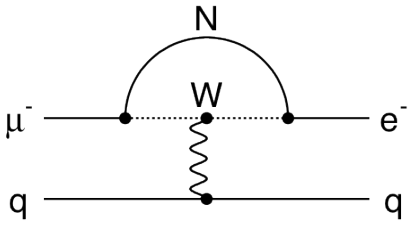
$$\sim \mathcal{O}(10^{-54})$$

Possible CLFV from NP models

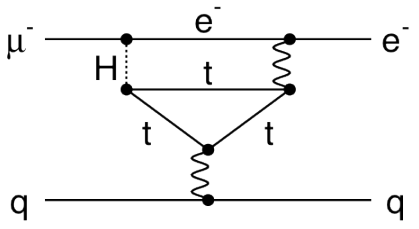
Loops




Supersymmetry

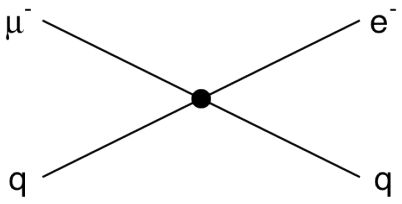



Heavy Neutrinos

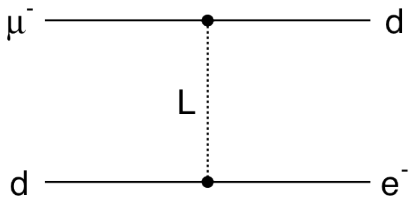



Extended higgs models

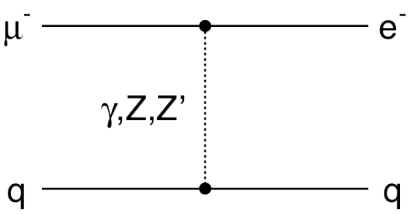
Contact Terms




Compositeness



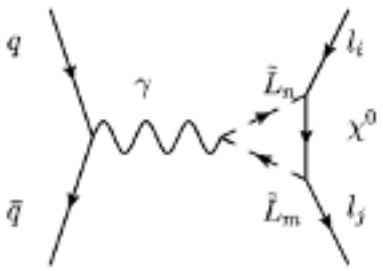

Leptoquarks

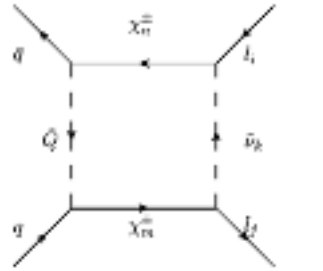



New Heavy Bosons / Anomalous Couplings

# Charged LFV in $J/\psi$ decays

- New physics models predicting BR($J/\psi \to e\mu$) to $10^{-16}$~$10^{-9}$, BR($J/\psi \to e\tau(\mu\tau)$) 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

| | $J/\psi$ number | $J/\psi \to e\mu$ | $J/\psi \to e\tau$ | $J/\psi \to \mu\tau$ |
|---|---|---|---|---|
| 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] BES Collaboration, Phys. Lett. B 561, 112007 (2003).
[8] BES Collaboration, Phys. Lett. B 598, 172 (2004).
[9] BESIII Collaboration, Phys. Rev. D 87, 112007 (2013).

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

Phys. Rev. D 103, 112007 (2021)

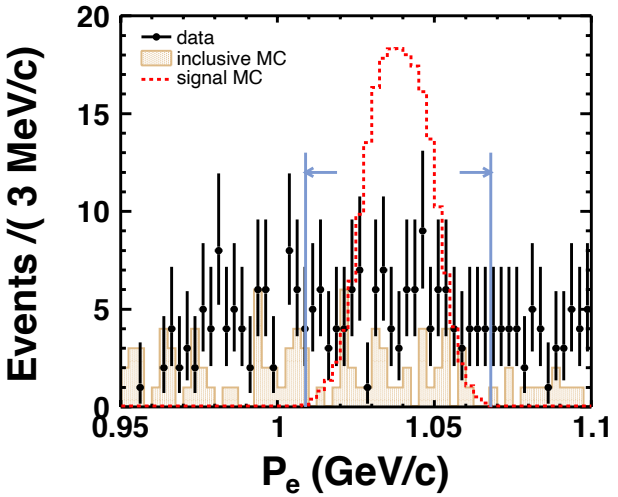
- **Based on 10 billion $J/\psi$ data set:**
  - **1310.6M collected @2009+2012 (sample I)**
  - **8774.01M collected @2017-2019 (sample II)**

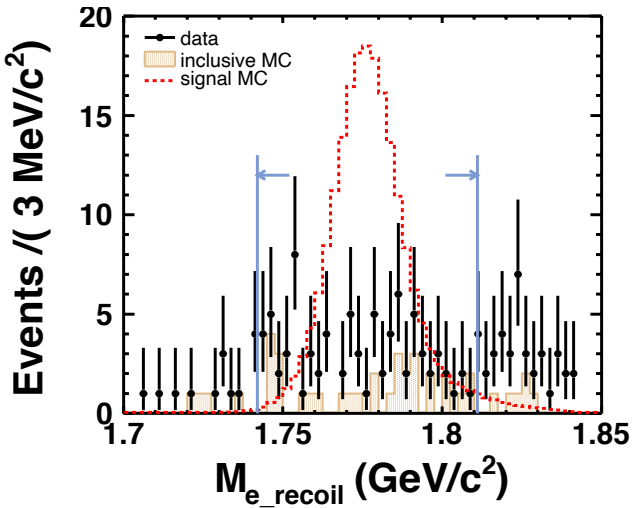
- **Searching process: $J/\psi \to e\tau,\ \tau \to \pi\pi^0\nu$**
  - **One electron and one charged pion.**
  - **At least two photon showers and one $\pi^0$.**
  - **Two-body-decay**
  - **One undetected neutrino with missing energy**

- **Blind analysis to avoid possible bias**

# Event selection: $J/\psi \to e^{\pm}\tau^{\mp}$

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



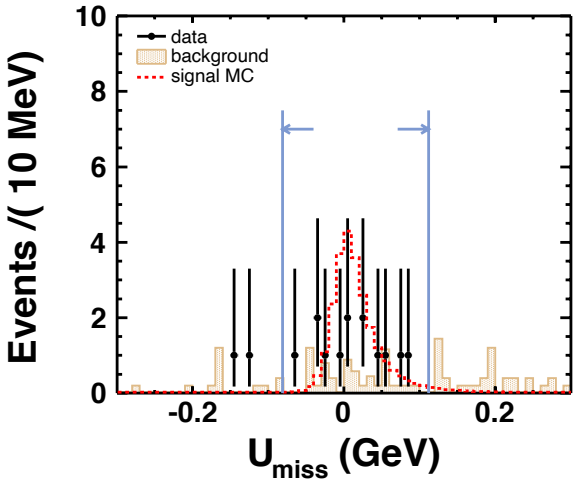



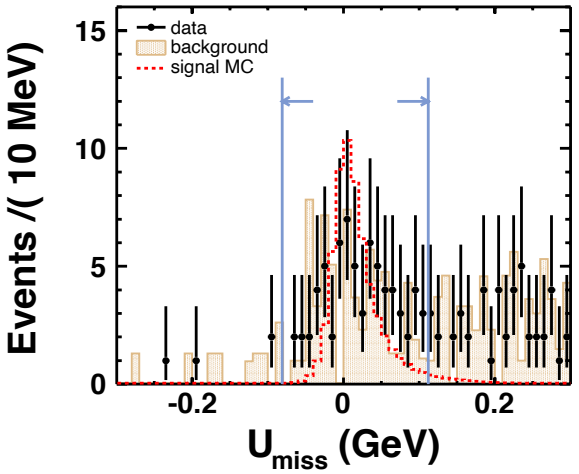
# Search for $J/\psi \to e^{\pm}\tau^{\mp}$

- Background from $J/\psi$ resonance and continuum process.

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

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




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

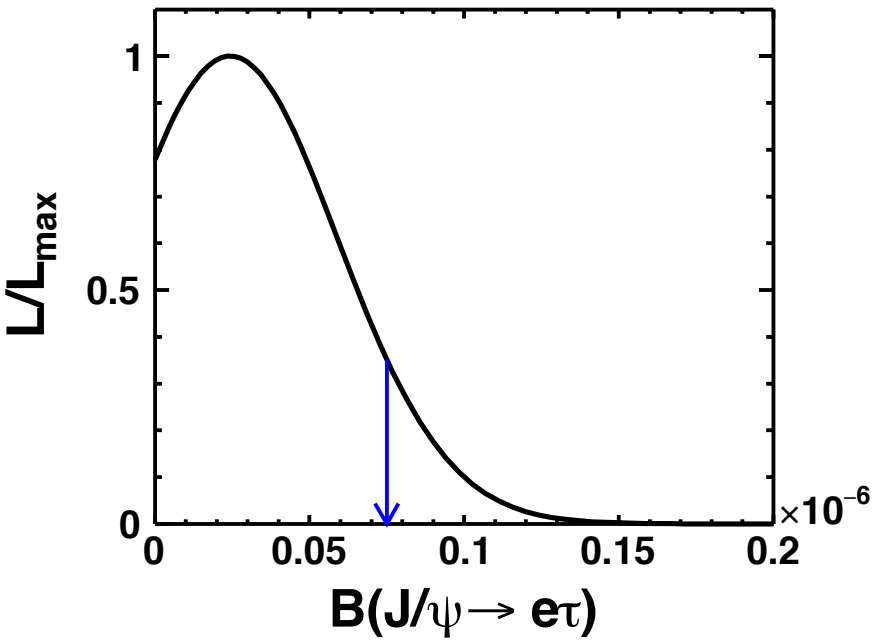
Phys. Rev. D 103, 112007 (2021)

# Sys. Uncertainty: $J/\psi \to e^{\pm}\tau^{\mp}$

| Sources | sample I | sample II |
|---|---|---|
| Number of $J/\psi$ | 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% |
| $\pi^0$ reconstruction* | 1.0% | 1.0% |
| $P_e$ and $M_{e\_recoil}$ requirements | 3.0% | 3.3% |
| $E_{\rm miss}$ requirement | 1.0% | 0.8% |
| Total uncertainty | 3.9% | 4.1% |

# Search Result: $J/\psi \to e^{\pm}\tau^{\mp}$

- Determination of upper limit at 90% C.L. with Bayesian method, assuming:
  - 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.
- The 1st published paper based on full 10 billion $J/\psi$ data of BESIII

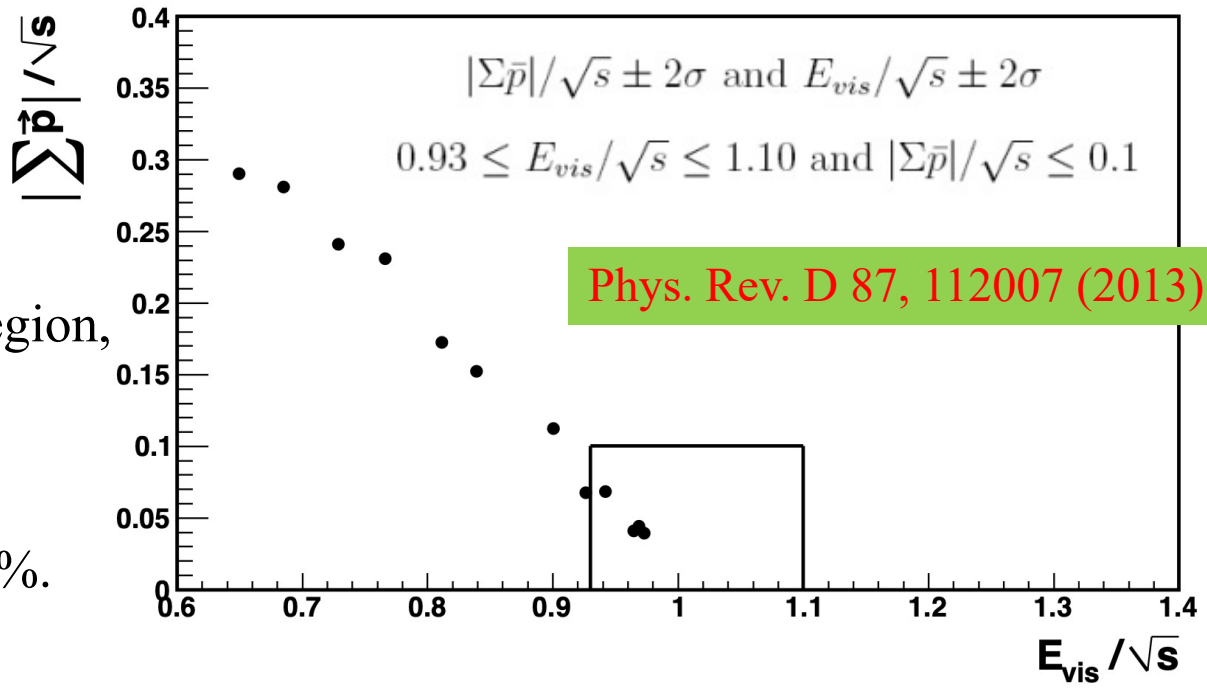



Phys. Rev. D 103, 112007 (2021)

# Search Result: $J/\psi \to e^{\pm}\mu^{\mp}$

- Data set: 225 million $J/\psi$.
- Two opposite charged tracks, no missing track.
- 4 candidates found in the signal region, consistent with background expectations ($4.75 \pm 1.09$).
- Total systematic uncertainty ~ 5.8%.
- Upper limit is obtained by the Feldman-Cousins method with systematic uncertainties included.
- Upper limit at 90% C.L.

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




Phys. Rev. D 87, 112007 (2013)

Update in progress:

- Data set: 10 billion $J/\psi$.
- Upper limit expectation $10^{-9}$~$10^{-8}$.

# Prospects: more cFLV channels

➢ $J/\psi \to e\tau$, $\tau \to \mu\nu_\mu\nu_\tau$ 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 expectation $\sim 10^{-8}$.

➢ $J/\psi \to \gamma e\tau$ 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 expectation $\sim 10^{-8}$.

**cLFV processes from $\psi$(2S), D, $\eta$ and $\eta'$ decays are also possibly to search at BESIII, esp for the coming final datasets**

# BESIII New Physics: Outlook

Extended running of another 5-8 years, with upgrade in both energy and lumi

BEPC-U under investigation: x3 in lumi

**Exotic Decays and New Physics**



**Future Physics Programme of BESIII**

*Chinese Phys. C* **44**, 040001 (2020).

- ✓ Further explore BESIII NP potential
  - •Near-threshold production
  - •High lumu
  - •Clean signals
- ✓ Produce more influential results with these advantages

**Open for new opportunity**

# Summary

- BESIII has a rich new physics search program
- charged LFV with the world largest $e^+e^-$ annihilation $J/\psi$. Latest results are reported:
  - $BR(J/\psi \to e\tau) < 7.5\times10^{-8}$ @ 90% C.L. Phys. Rev. D 103, 112007 (2021)
    - The 1st publication with 10B $J/\psi$ sample
  - $BR(J/\psi \to e\mu) < 1.6\times10^{-7}$ @ 90% C.L. Phys. Rev. D 87, 112007 (2013)
    - With 225M $J/\psi$ sample
    - In updates with 10B data: $10^{-9}\sim10^{-8}$
- Better/more constraints on LFV processes can be expected from BESIII in future.

...More to come!

# Thanks!