

# CLFV at EIC

EICへの素粒子分野からの興味

# 前置き

## 特に、素粒子/原子核の境界領域の観点から

- EIC project のメインストリーム
  - 陽子・原子核構造
  - 陽子スピン構造 QCDの物理
  - グルーオン飽和
- その他の期待されるアウトプット 素粒子分野では  
それなりにactiveな領域
  - 素粒子との境界領域
    - Weinberg angle measurement :  $\sin^2 \theta_w$
    - Charged lepton flavor violation :  $e-\tau$  transition

コライダーの強み・弱み(?)

多様なアウトプット

予算＋共同研究者が必要

# Snowmass2021

## 素粒子分野の議論

- CLFV WG
  - EICの記載
  - $e-\tau$  transition

素粒子分野の議論で  
“EIC”の記載がある  
ことが重要

The screenshot shows the Snowmass2021 website navigation menu. It is organized into several sections:

- Navigation:** WELCOME PAGE, ANNOUNCEMENTS, SNOWMASS CALENDAR, ETHICS GUIDELINES.
- Organization:** SNOWMASS ADVISORY GROUP, SNOWMASS STEERING GROUP, FRONTIER CONVENERS, APS DPF SNOWMASS PAGE, SNOWMASS EARLY CAREER.
- Snowmass Frontiers:** ENERGY FRONTIER, NEUTRINO PHYSICS FRONTIER, RARE PROCESSES AND PRECISION, COSMIC FRONTIER, THEORY FRONTIER, ACCELERATOR FRONTIER, INSTRUMENTATION FRONTIER, COMPUTATIONAL FRONTIER, UNDERGROUND FACILITIES, COMMUNITY ENGAGEMENT FRONTIER, LIAISONS.
- Community Contributions:** LETTERS OF INTEREST, CONTRIBUTED PAPERS.
- Search:** A search bar with the text "Search".
- HELP:** Communication Types and Access, Monte Carlo simulations, How to Edit This Wiki, Contact Information, Recent Changes.

<https://snowmass21.org/rare/clfv>

## RF5: Charged Lepton Flavor Violation (electrons, muons and taus)

–Table of Contents

- RF5: Charged Lepton Flavor Violation (electrons, muons and taus)
  - Description
  - Upcoming meetings
  - Contributions
  - Relevant References

Co-conveners	<a href="#">Sacha Davidson (Lyon)</a> , <a href="#">Bertrand Echenard (Caltech)</a>
Mailing-list	<a href="mailto:SNOWMASS-RPF-05-CLFV@FNAL.GOV">SNOWMASS-RPF-05-CLFV@FNAL.GOV</a> (instructions)
Slack channel	<a href="#">rpf-05-clfv</a> (instructions)
Next Event	Decays of heavy states (h,t,Z,Z'...) September 3 @ 8h00 PT / 10h00 CT / 17h00 CET – Agenda TBA  <b>The meson and baryon decay workshop (August 13) is postponed to September 28-29</b>

### Description

This topical group will address experimental and theoretical aspects of:

1. Muon and tau LFV reactions ( $\mu \rightarrow e \gamma$ ,  $\mu \rightarrow 3e$ ,  $\mu-e$  conversion, tau decays)
2. Muonium-antimuonium oscillations and LFV leptonium decays
3. Meson and baryon LFV decays ( $K \rightarrow \pi e \mu$ ,  $B \rightarrow K \tau e$ , ...)
4. Decays of heavy states (h,t,Z,Z'...) and other LFV processes at colliders
5. Light to heavy lepton LFV transitions (EIC, muon beam,...)

This topical group will benefit from the synergies with other study groups, including

- RF01 / RF02: Weak decays of b and c quarks and weak decays of strange and light quarks
- EF02/ EF09: EW Physics: Higgs Boson as a portal to new physics and BSM: More general explorations
- AF05: Accelerators for PBC and Rare Processes

### Upcoming meetings

The CFLV group will organize the following workshops (August and September dates are still tentative)

- July 2, 2020, Muon transitions and decays, muonium-antimuonium ([Agenda](#))
- ~~July 23, 2020, Tau decays and transitions ([Agenda](#))~~
- September 3, 2020, Heavy states decays
- September 28-29, 2020, LFV and LFU in meson and baryon decays with RF01/RF02
- TBA, CLFV with high intensity muon factory

Recording of the workshop will be posted on indico. Please [email us](#) if you wish to give a presentation

# RF05: CLFV - Tau Decays and Transitions

Thursday Jul 23, 2020, 10:00 AM → 2:00 PM US/Central

Zoom

Bertrand Echenard (Caltech), Sacha Davidson (IN2P3)





**Description** This workshop will discuss theoretical and experimental aspects of Charged Lepton Flavor Violation in tau transitions and decays.

This meeting is part of a series of events in the context of Snowmass-2021. More information on the CLFV topical group and the schedule of the upcoming workshops can be found at this location: <https://snowmass21.org/rare/clfv>

Connection information: [Click here](#)

Feel free to contact the group conveners if you have any question or comment.

10:00 AM	→ 10:10 AM	<b>Introduction</b>	🕒 10m
<p><b>Speakers:</b> Bertrand Echenard (Caltech), Sacha Davidson (IN2P3)</p> <p>Workshop-tau-intro...</p>			
10:10 AM	→ 10:40 AM	<b>Theory overview: CLFV at tau scale</b>	🕒 30m
<p><b>Speaker:</b> Vincenzo Cirigliano (Los Alamos National Laboratory)</p> <p>P5TauCirigliano.pdf</p>			
10:40 AM	→ 11:00 AM	<b>Tau LFV decays: Super Tau Charm Factory</b>	🕒 20m
<p><b>Speaker:</b> Dr Xiaorong Zhou (USTC)</p> <p>cLFV_tau_STCF.pdf</p>			
11:00 AM	→ 11:20 AM	<b>Tau LFV decays: FCC-ee perspectives</b>	🕒 20m
<p><b>Speaker:</b> Mogens Dam (Niels Bohr Institute, Copenhagen University)</p> <p>Snowmass-clfv-20...</p>			
11:20 AM	→ 11:50 AM	<b>Mono tau production at LHC</b>	🕒 30m
<p><b>Speaker:</b> Dr Greljo Admir (CERN)</p> <p>snowmass_GreljoA...</p>			
11:50 AM	→ 12:10 PM	<b>Break</b>	🕒 20m

11:50 AM	→ 12:10 PM	Break	🕒 20m
12:10 PM	→ 12:30 PM	<b>TauFV: a fixed-target experiment to search for LFV tau decays</b> Speaker: Prof. Guy Wilkinson (Unoversity of oxford)  TauFV_snowmass_...	🕒 20m
12:30 PM	→ 12:50 PM	<b>Tau LFV decays: LHC experiments</b> Speaker: Dr Jian Wang (University of Florida)  tau3mu_Jian_23Ju...	🕒 20m
12:50 PM	→ 1:20 PM	<b>Tau LFV decays: Belle II</b> Speaker: Swagato Banerjee (University of Louisville)  Snowmass_23July...	🕒 30m
1:20 PM	→ 1:40 PM	<b>Electron-to-tau transition at EIC</b> Speaker: Dr Jinlong Zhang (Stony Brook)  clv_snowmass_eta...	🕒 20m
1:40 PM	→ 2:00 PM	Discussion	🕒 20m

# CLFV

## ざっくりと

- Decayで見る：重いものから軽いものへ

- 代表的にはミューオン稀崩壊

$$\mu^+ \rightarrow e^+ \gamma$$

- タウも同様

$$\mu^+ \rightarrow e^+ e^+ e^-$$

- 転換過程

- 特にミューオン

$$\mu^- N \rightarrow e^- N$$

- ミューオニウム

- 反ミューオニウム転換

$$\mu^+ e^- \rightarrow \mu^- e^+$$

- 伝統的な手法

- ゲージボソン

$$Z \rightarrow e\mu$$

- ヒッグス

$$H \rightarrow \mu\tau$$

- K/B decays

# CLFV 相互作用

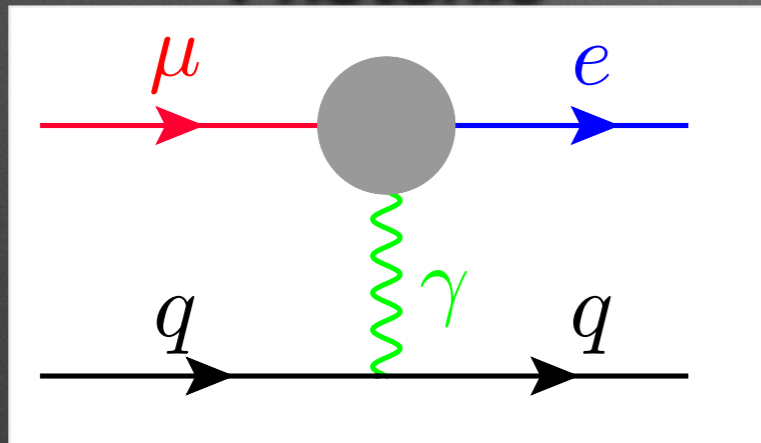
## 有効 Lagrangian

$\kappa$  : photonic ( $\kappa \ll 1$ ), non-photonic ( $\kappa \gg 1$ )

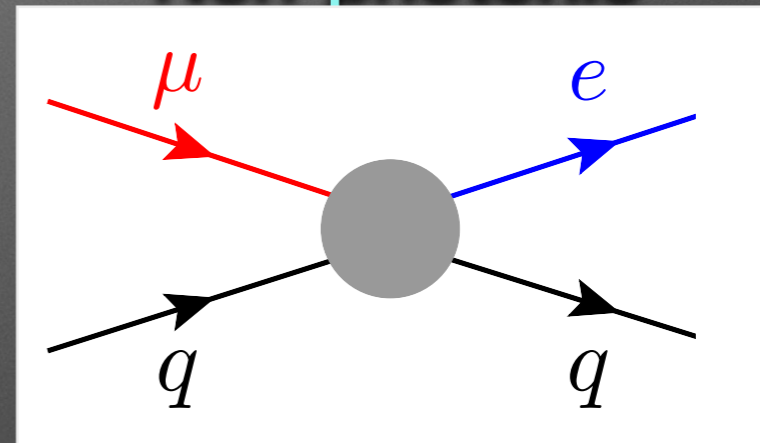
$\Lambda$  : 有効エネルギースケール

$$\mathcal{L} = \frac{1}{1 + \kappa} \frac{m_\mu}{\Lambda^2} \bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu} + \frac{\kappa}{1 + \kappa} \frac{1}{\Lambda^2} (\bar{\mu}_L \gamma^\mu e_L) (\bar{q}_L \gamma^\mu q_L)$$

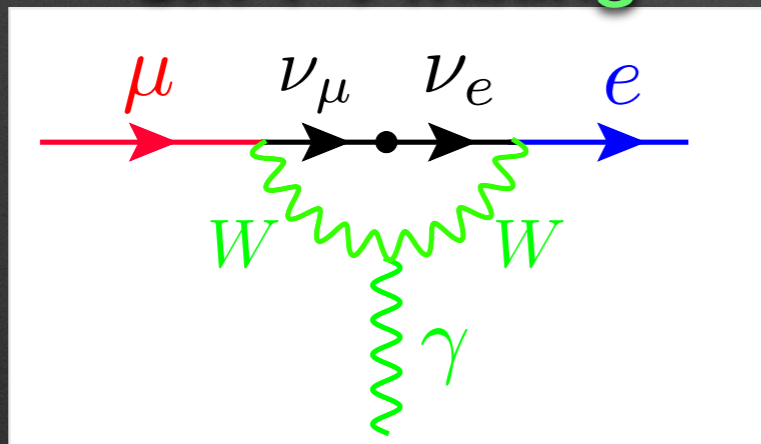
Photonic



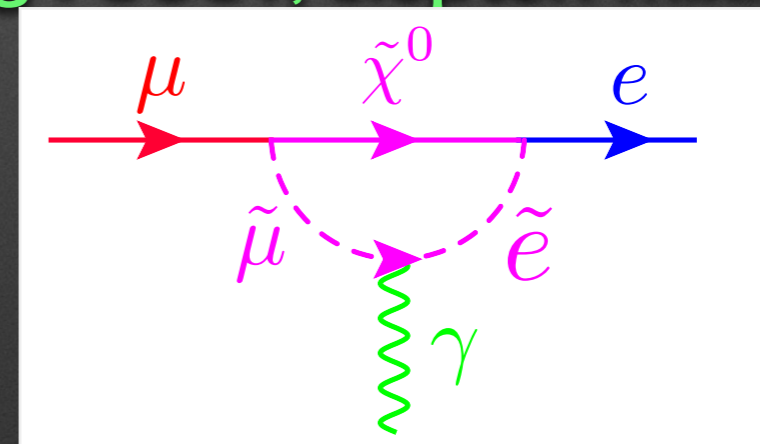
Non-photonic



SM +  $\nu$  mixing



Eg : SUSY, slepton mixing



$Br(\mu \rightarrow e\gamma) < 10^{-54}$   
 GIM-suppressed

BSM !

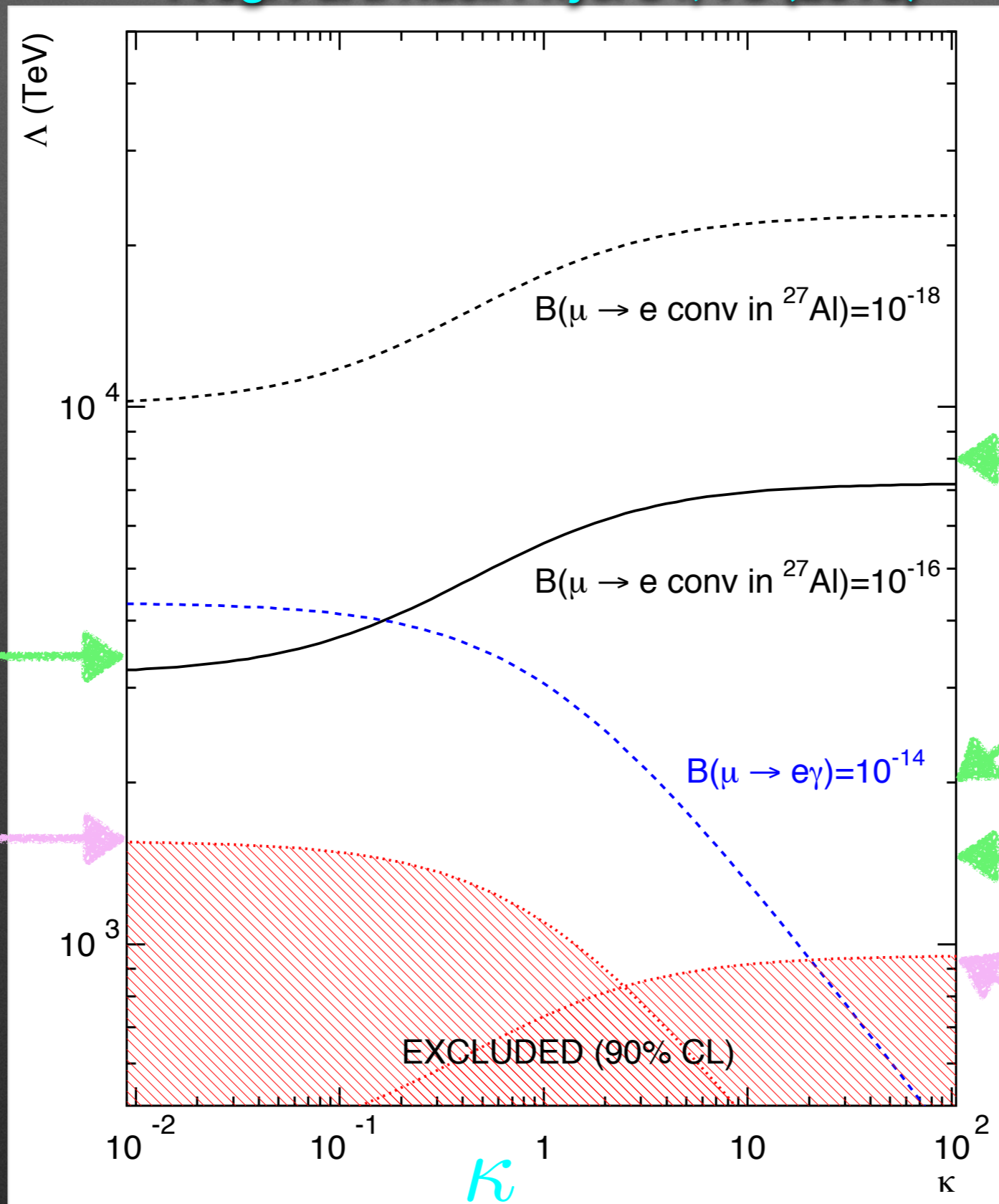
**SM-background free**

# CLFV 実験の BSM 発見感度

T. P. Gorringer, D. W. Hertzog,  
 Prog. Part. Nucl. Phys. 84, 73 (2015)

$$\mu^+ \rightarrow e^+ \gamma$$

$$\mu^- N \rightarrow e^- N$$



MEG II  
 $5 \times 10^{-14}$

MEG (2013)  
 $5.7 \times 10^{-13}$

Phys. Rev. Lett. 110,  
 201801 (2013)

COMET Phase-II  
 Mu2e  
 $6 \times 10^{-17}$

COMET Phase-I  
 $7 \times 10^{-15}$

DeeMe  
 $1 \times 10^{-14} - 5 \times 10^{-15}$

SINDRUM II (2006)  
 $7 \times 10^{-13}$

Eur. Phys. J. C47, 337 (2006)

Photonic

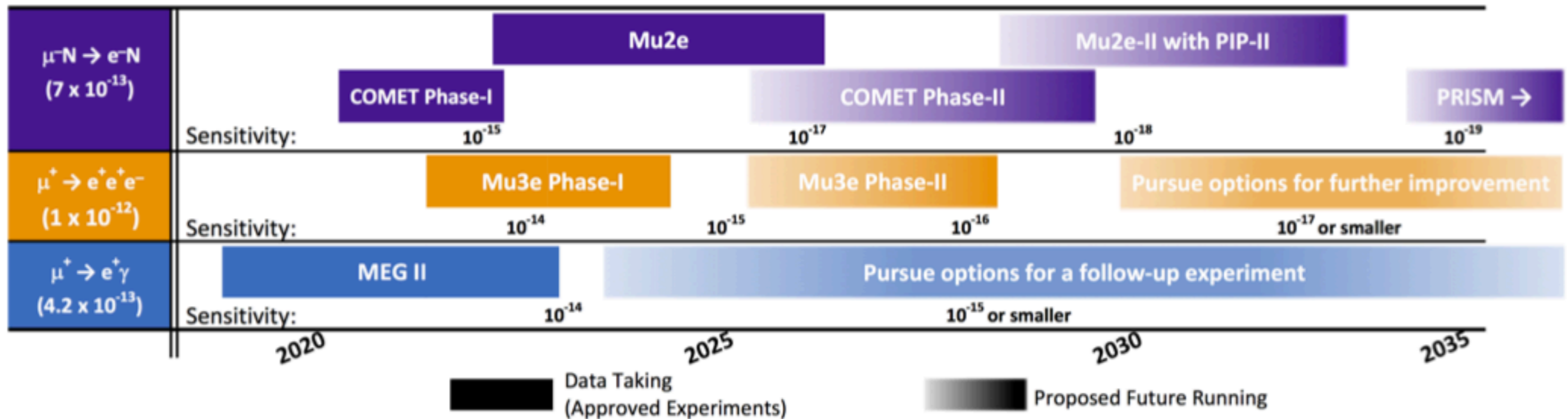
Non-photonic



# ミュオン CLFV

## 2020 European Strategy Update

Searches for Charged-Lepton Flavor Violation in Experiments using Intense Muon Beams



Snowmass 2021 mini-workshop  
CLFV - Tau Decays and Transitions  
July 23 2020

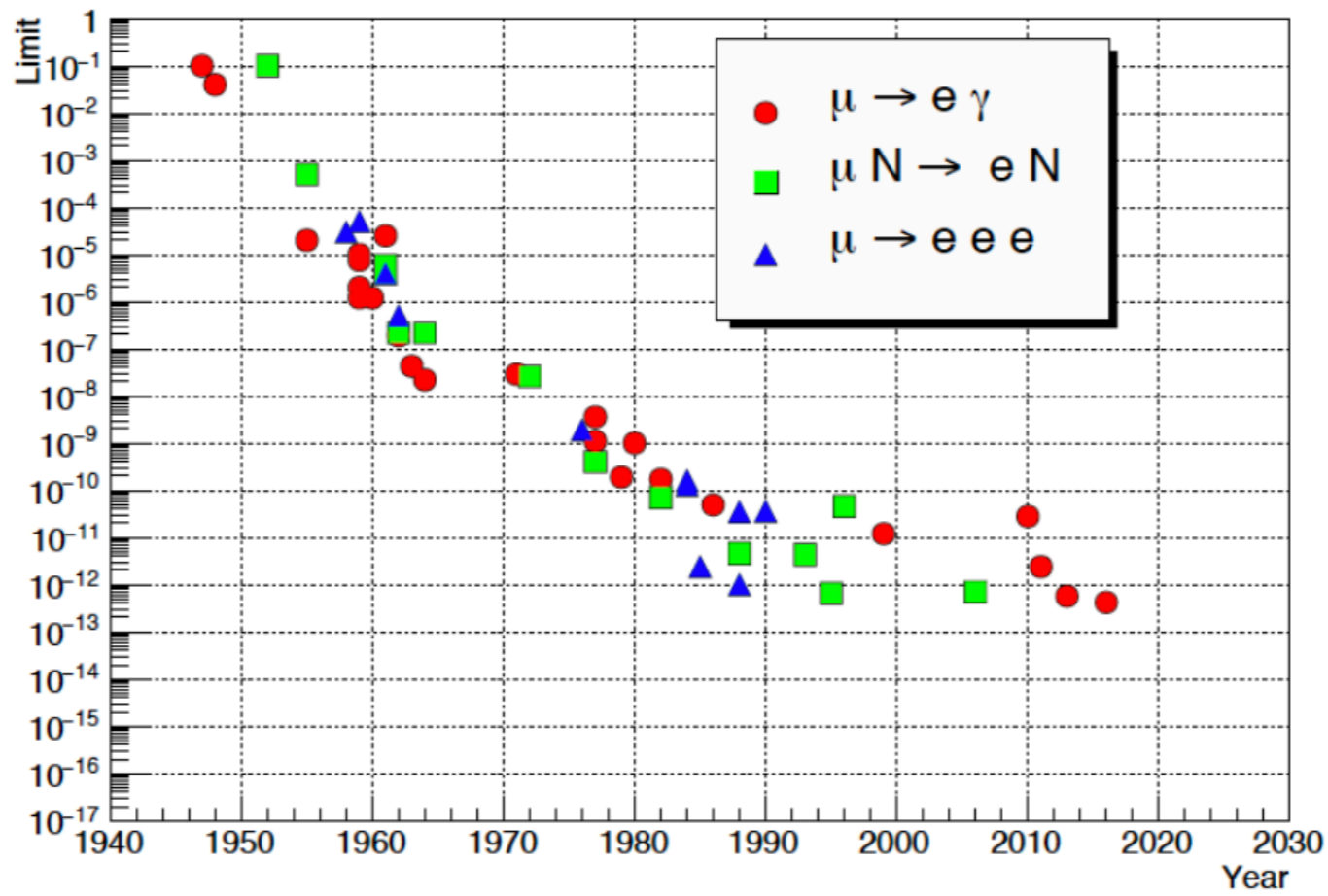
# Theory overview: CLFV at the $\tau$ scale

**Vincenzo Cirigliano**  
Los Alamos National Laboratory



# Muon processes

$$\mu \rightarrow e\gamma, \quad \mu \rightarrow e\bar{e}e, \quad \mu(A, Z) \rightarrow e(A, Z)$$



Calibbi-Signorelli  
1709.00294

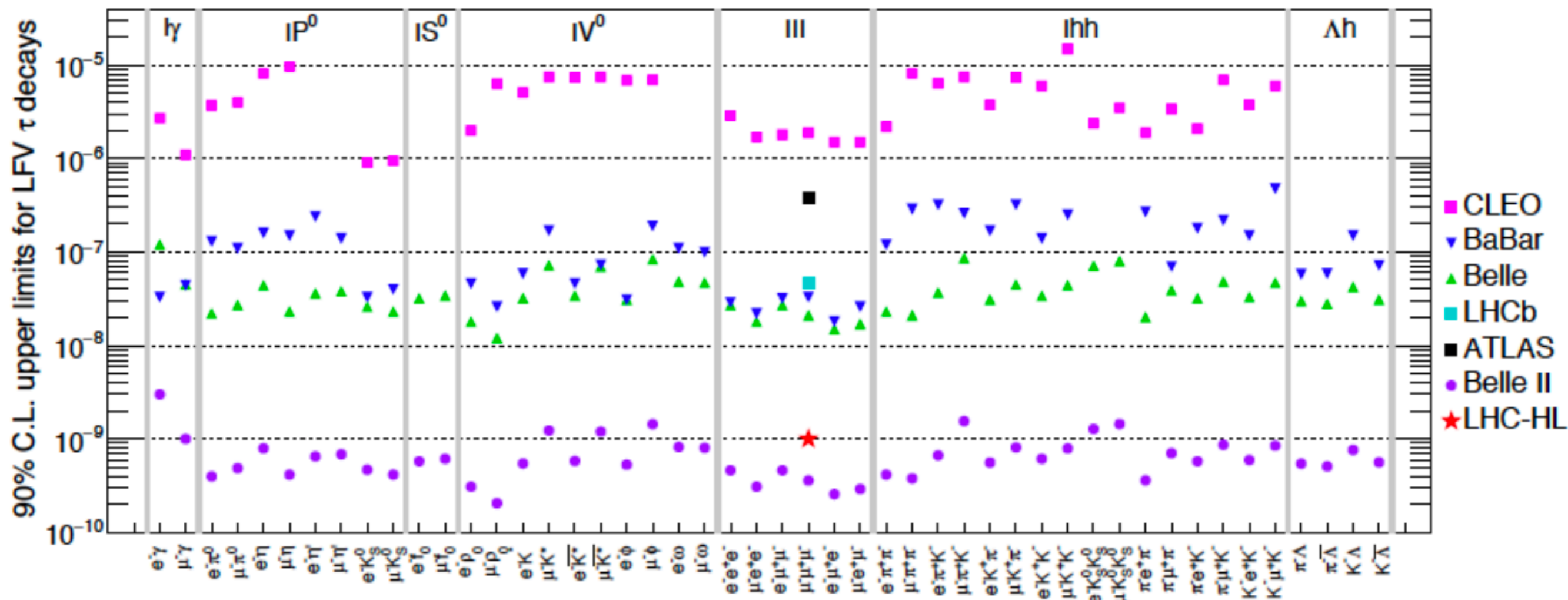
90% CL

$B_{\mu \rightarrow e\gamma}$	$< 4.2 \times 10^{-13}$	$\longrightarrow$	$10^{-14}$ (MEG at PSI)
$B_{\mu \rightarrow 3e}$	$< 1.0 \times 10^{-12}$	$\longrightarrow$	$10^{-15/16}$ (PSI)
$B_{\mu \rightarrow e}^{Ti}$	$< 4.3 \times 10^{-12}$	$\longrightarrow$	$10^{-16/17 \rightarrow -18}$ (Mu2e, COMET)

# Tau decays

$$\tau \rightarrow l\gamma, \quad \tau \rightarrow l_{\alpha} \bar{l}_{\beta} l_{\beta}, \quad \tau \rightarrow l Y \quad Y = P, S, V, P\bar{P}, \dots$$

HFLAG-tau → Belle-II Physics Book I808.I0567 ; Flavor @ HL/HE LHC I912.07638



Rich(er) landscape! Access to hadronic modes.

$10^{-9}$  (or better) sensitivities at Belle-II, LHC-HL, and other future facilities

# Conclusions & Outlook

- Charged LFV processes are great probes of new physics
  - *Discovery* tools: clean, high scale reach
  - *Model-diagnosing* tools: mediators, sources of flavor breaking
- Tau decays offer a rich arena to discover and diagnose CLFV
  - In general, no theoretical ‘golden mode’
  - Besides  $\tau \rightarrow \mu \gamma$ ,  $\tau \rightarrow 3\mu$ , hadronic modes such as  $\tau \rightarrow \mu(e)\pi\pi\pi$  can be quite interesting (e.g. imprint of Higgs couplings) and are relatively clean theoretically

Looking forward to the next decade:

- ★ 1-2 (3-4) orders of magnitude improvement in  $\tau$  ( $\mu$ ) processes
- ★ Colliders (LHC, EIC) can play a significant role ( $h \rightarrow \tau\mu$ ,  $e \rightarrow \tau$ )

# CLFV at EIC

## ざっくりと

- $e$ - $\tau$  transition : 軽いものから重いものへ
  - HERA ZEUS/H1 では結果がある
  - EICでフロンティアへ(?)



The diagram shows a circular electron storage ring with several key components labeled: Electron Injection Line, Electron Storage Ring, Electron Cooler, Linear Electron Accelerator, Polarized Electron Source, and Possible Detector Location. The ring is depicted with multiple concentric paths in different colors (red, yellow, blue, green).

**Stony Brook University**

**Center for Frontiers in Nuclear Science**

## Electron-to-Tau Transition at EIC

Jinlong Zhang (SBU/CFNS)

Based on ongoing work with Abhay Deshpande (SBU/BNL/CFNS), Jin Huang (BNL), Krishna Kumar (UMass, Amherst), Yuxiang Zhao (IMP,CAS)

Snowmass-2021 CLFV workshop  
July 23, 2020

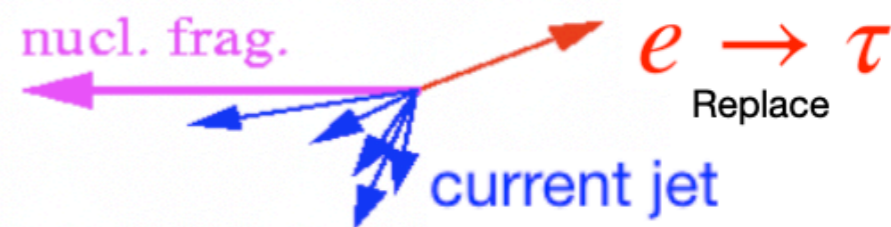
# CFLV in EIC: $e \rightarrow \tau$ Transition

- While CLFV(1,2) is stringently constrained, limits on CLFV(1,3) are weaker by several orders of magnitude. 1-3世代間

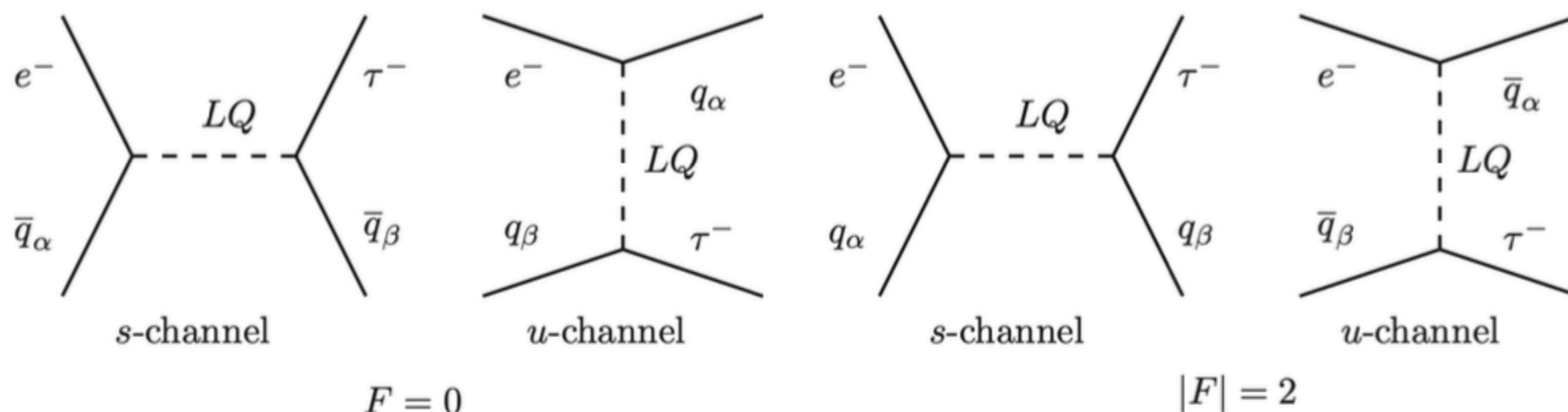
- Various models predict enhanced sensitivity for CLFV(1,3) while suppressing CLFV(1,2)

- CFLV in DIS:

$$e + p \rightarrow \tau + X$$



- **Leptoquark** models provide a good benchmark to study sensitivity
  - CLFV at tree level processes; allow coupling between same and different generations of quarks and leptons at initial state and final state

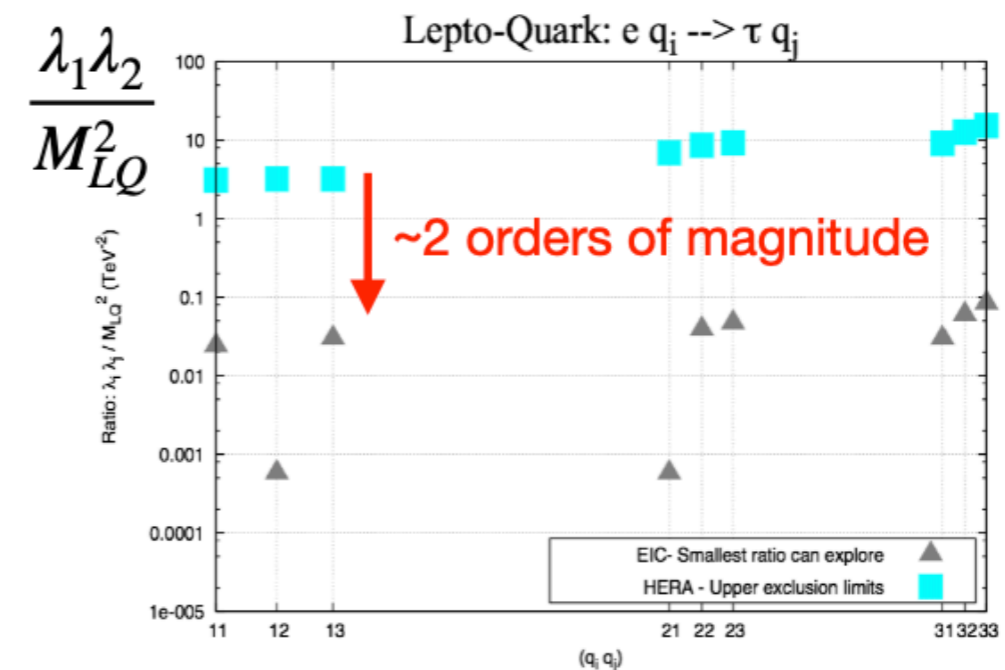


# $e \rightarrow \tau$ mediated by LQs in DIS

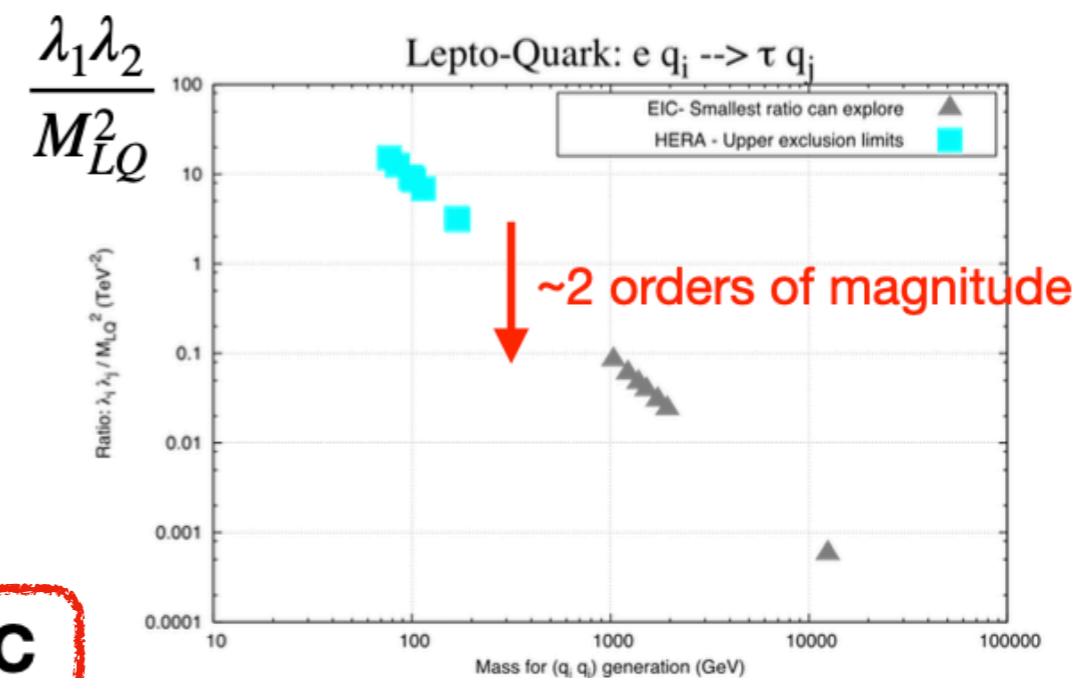
- At HERA, the first electron-proton collider, H1 and ZEUS have searched for Leptoquarks (CLFV) and set limits

- $\sqrt{s} \sim 320$  GeV
- Luminosity  $\sim 10^{30-31}$  cm<sup>-2</sup>s<sup>-1</sup>
- Dataset:  $\sim 0.5$  fb<sup>-1</sup>

- First phenomenological study for CLFV mediated by LQs at EIC done by Gonderinger, Ramsey-Musolf, JHEP (2010) 2010: 45
- At the EIC, with much higher luminosity,  $10^{30-31} \rightarrow 10^{33-34}$  cm<sup>-2</sup>s<sup>-1</sup>,  $\sim 2$  orders of magnitude improvement of the sensitivity comparing to HERA is expected



Assume 0.1 fb cross-section sensitivity

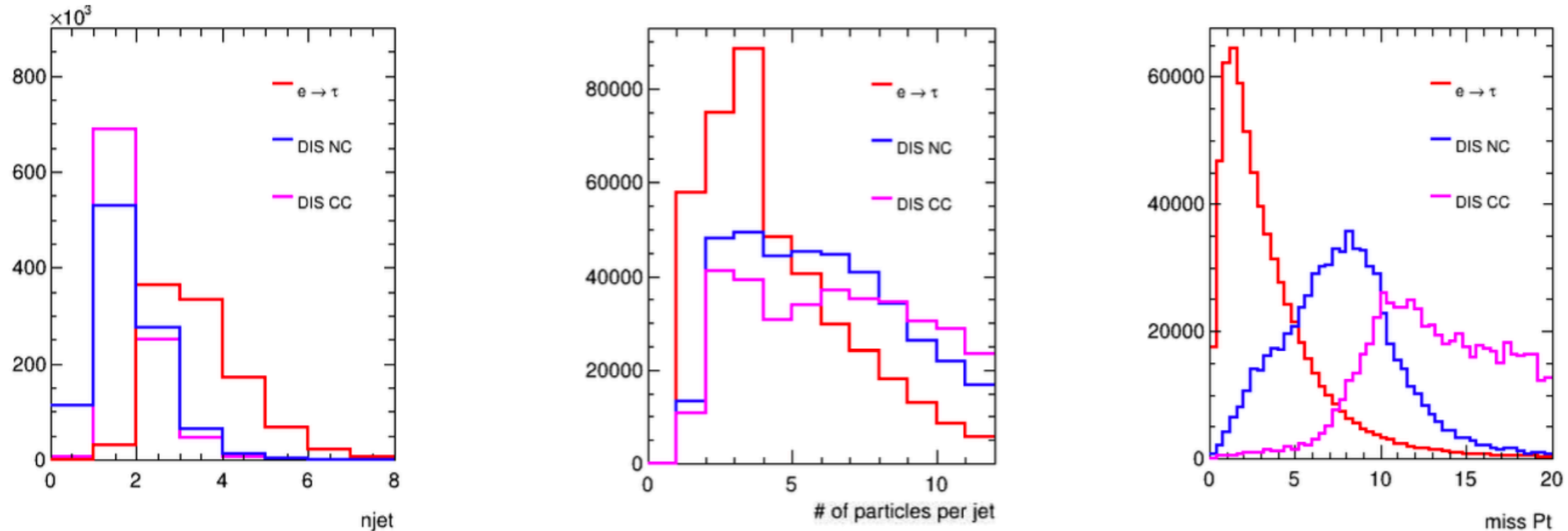


**New discovery space:  $e \rightarrow \tau$  transition at EIC**



# Features of LQ $e \rightarrow \tau$ event

18x275 GeV<sup>2</sup>



Note: electron in DIS NC is masked; Fastjet, Anti- $k_T$ ,  $R = 1.0$ ; jet  $pt > 2$  GeV;  $Q^2 > 100$  GeV<sup>2</sup>

- $e \rightarrow \tau$  event
  - 2+ jets
  - Low particle multiplicity
  - Modest missing  $p_T$  (partial of tau  $p_T$ )
- DIS event
  - 1 jets dominating
  - Higher particle multiplicity
  - Missing  $p_T \sim$  lepton  $p_T$

# まとめではないですが...

## 素粒子分野との協力を模索すると...

- 魅力的なテーマ
  - $e-\tau$  transition
  - Weinberg angle measurement
  - Parity violating asymmetry in ep
  - 他にもあるかも

