中国科学技术大学
University of Science and Technology of China

Tau LFV decays at Super Tau-Charm Facility

Xiaorong Zhou
(on behalf of STCF working group)
University of Science and Technology of China

Snowmass, 2020.7.23

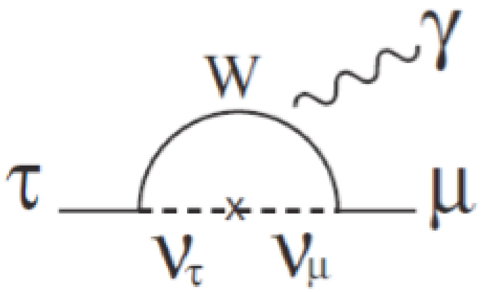
Lepton Flavor Conservation

中国科学技术大学
University of Science and Technology of China

- **In quark sector**: flavor mixing is well established
- **Neutrino mixing**: =>lepton flavor symmetry is violated (a sign of LFV beyond the SM!)

How about charged lepton sector??

- The charged LFV processes can occur through oscillations in loops
- Immeasurable small rates (10^{-54}-10^{-49}) for all the LFV μ and τ decays



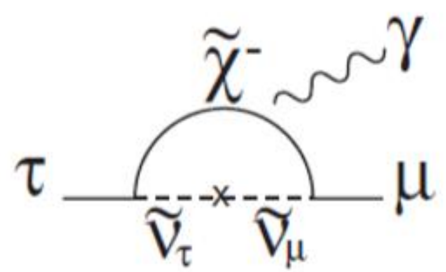
$$\mathfrak{B}(l_1 \to l_2\gamma) \propto \alpha\left(\frac{\Delta m^2}{m_W^2}\right)^2$$

Any observation of LFV in charged lepton will be a signature of NP !

LFV: a gateway to BSM

- Many extensions of SM naturally introduces cLFV at order ~**10^{-7} – 10^{-10}** (an crucial place to test BSM)

Model	Ref.	τ→μγ	τ→μμμ
SM + heavy majorana	PRD 66.034008	10^{-9}	10^{-10}
Non-universal Z′	PLB 547(3)252	10^{-9}	10^{-8}
SUSY + seesaw	PRL 89:241802	10^{-10}	10^{-7}
SM + 4th generation	arXiv.1006.530 6	10^{-8}	10^{-8}

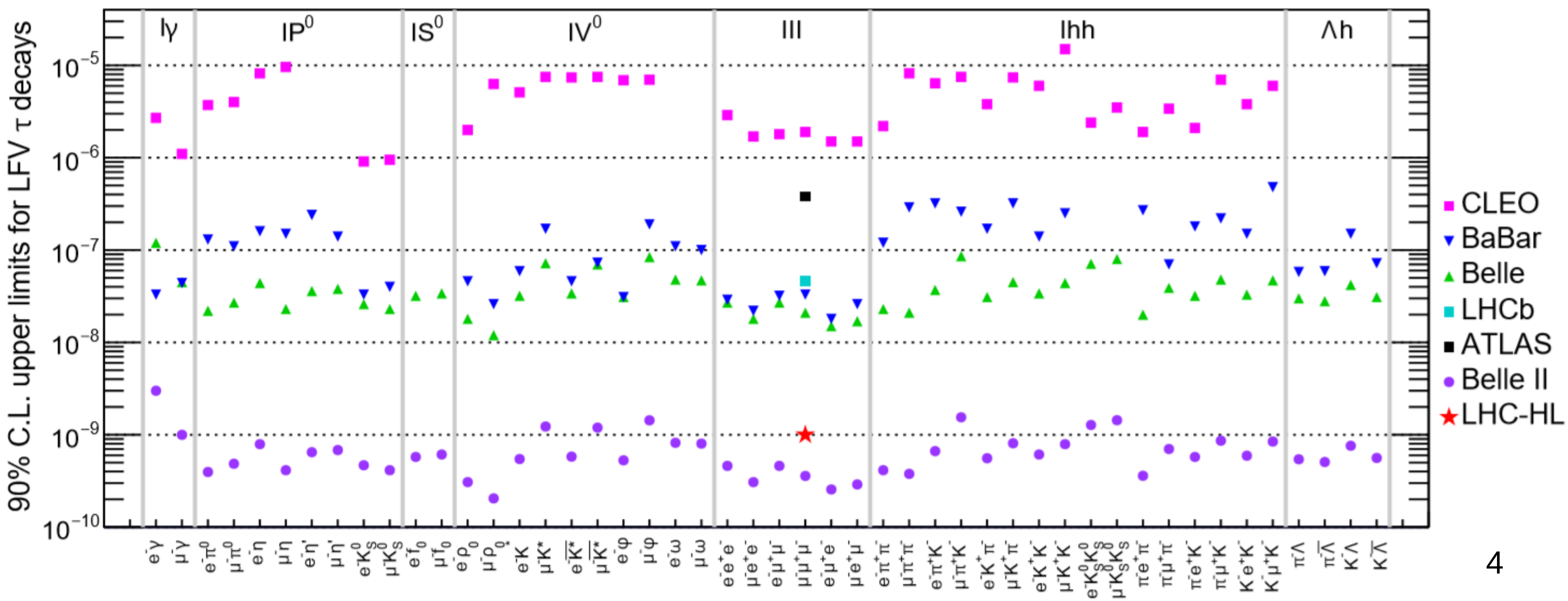


- Different cLFV experiments are necessary (as a part of 'global' programme): $l_i \to l_j\gamma$, $l_i \to l_j l_k l_k$, $\tau \to lh$…

τ LFV searches

University of Science and Technology of China

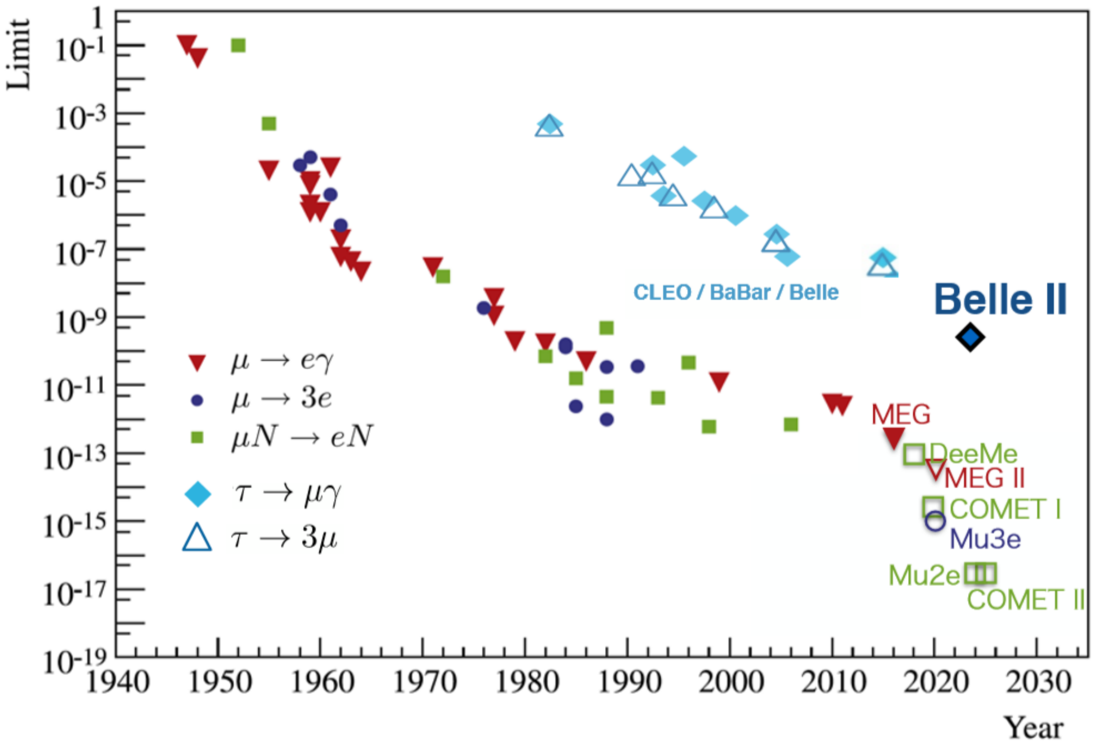
- τ—the heaviest charged lepton:
  - Various decay modes for LFV search, include decay to hadron
  - Strength of interaction relate to new physics is naively expected to be mass-dependent
  - $\tau \to l\gamma$ and $\tau \to lll$ are golden mode, which are expected to have largest branching fraction



CERN Yellow Rep.Monogr. 7 (2019) 867-1158

Evolution of limits

- Very rich experimental programme with substantial improvements expected in near future.
- Remarkable progress expected on Muon LFV searches.
- B factories expected to be the most powerful for tau LFV .



How about LFV at Super tau-charm factory?

Proposed STCF in China

中国科学技术大学
University of Science and Technology of China

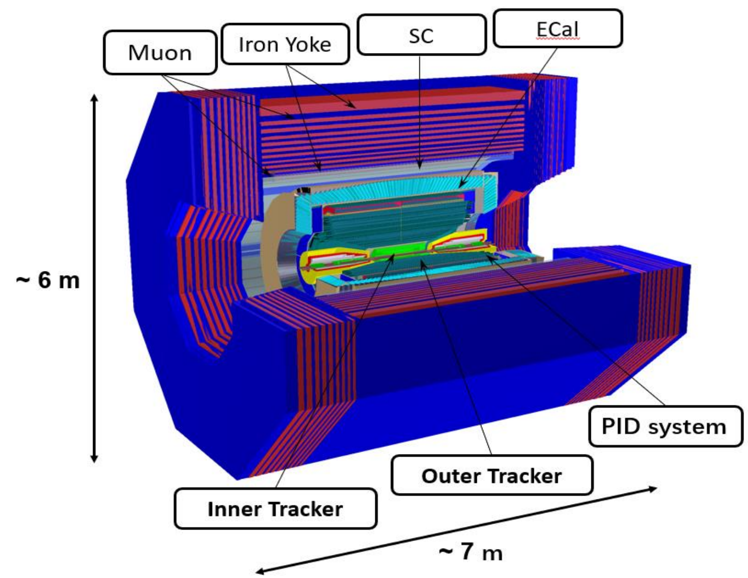
- Peaking luminosity (0.5-1)×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
- Energy range E_{cm} = 2-7 GeV
- Potential to increase luminosity and realize beam polarization

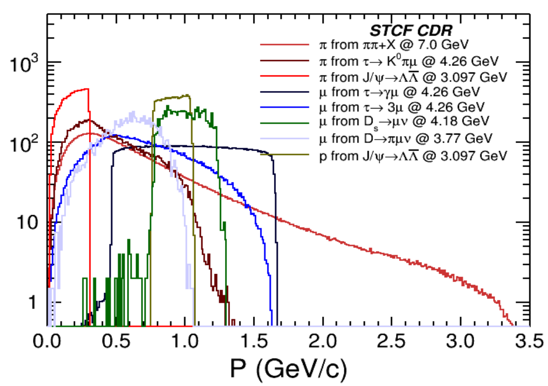
Parameters	Achieved Now
Circumference/m	707.258
Beam Energy/GeV	2; 1-3.5tunable
Current/A	1.5
Emittance$(\varepsilon_x/\varepsilon_y)$/nm·rad	2.85/0.0285
β Function @ IP (β_x^*/β_y^*)/mm	65/0.68
ν_x/υ_y	30.52259316 / 28.53792761
Collision Angle(full θ)/mrad	60
Momentum compaction factor	0.001237
Energy spread	4.034e-4
Tune Shift ξ_y	0.06 (estimated)
Hour-glass Factor	0.8 (estimated)
Luminosity/×$10^{35}cm^{-2}s^{-1}$	0.95 (estimated)

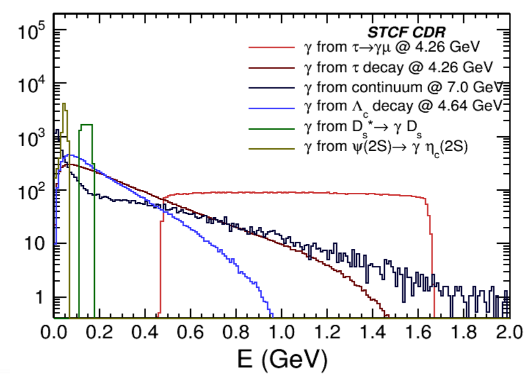
STCF Detector

中国科学技术大学
University of Science and Technology of China

- **Inner Tracker**
  - ~0.15% X0 / layer
  - σxy ~ 50 um
- **Out Tracker**
  - σxy~130 um, σp/p~0.5%@1GeV/c
  - dE/dx ~ 6%
- **PID system**
  - π/K (K/P) 3-4σ separation up to 2 GeV/c
- **Electromagnetic Calorimeter**
  - Range: 0.02 – 3 GeV
  - Resolution (1GeV): 2.5% (barrel) and 4% (endcap)
- **Muon system**
  - Pion suppression power: >10 and lower to 0.4 GeV/c





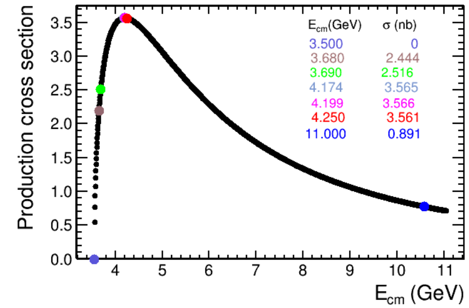


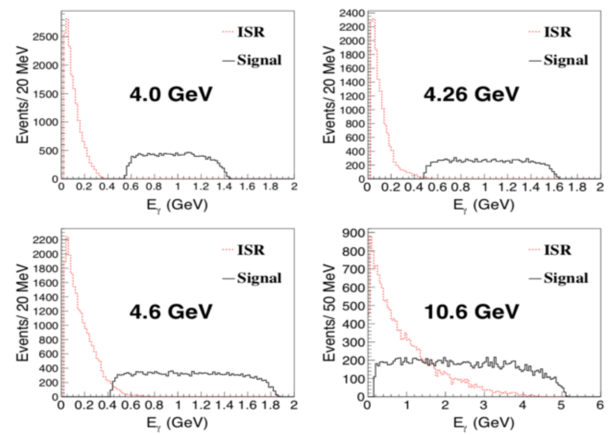
Studies of τ at STCF

University of Science and Technology of China

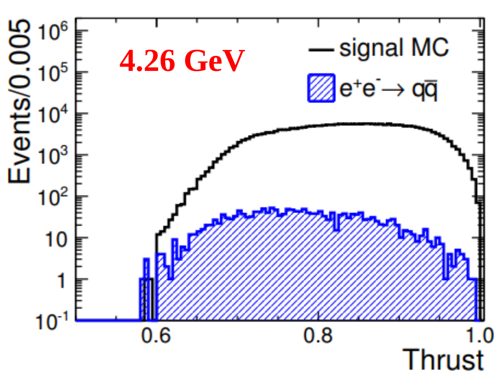
- **Advantage**:
  - Threshold production
  - Peaking cross section in 4-5 GeV
  - At 4.26 GeV, number of tau pairs per year:

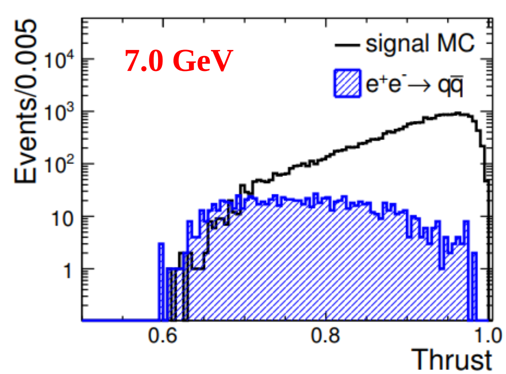
    $N_{\tau\tau} \sim$ **1.0 ab^{-1} ×3.5 nb = 3.5× 10^9**
  - $e^+e^- \to \gamma\tau^+\tau^-$ is not the main background
  - Improved π/μ misid rate at STCF
- **Disadvantage**:
  - Entangled topology of $e^+e^- \to \tau^+\tau^-$
  - Large $e^+e^- \to q\bar{q}$ background at low c.m.e



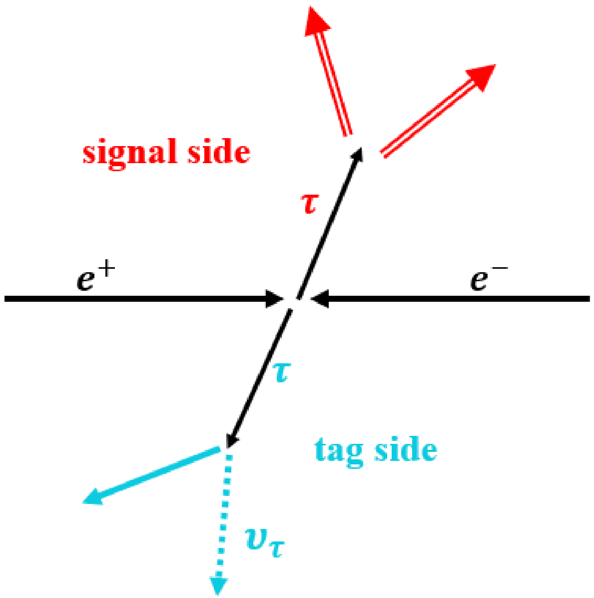


$$T \equiv max_{\vec{n}} \frac{\sum_i |\vec{n} \cdot \vec{p}_i|}{\sum_i |\vec{p}_i|}$$

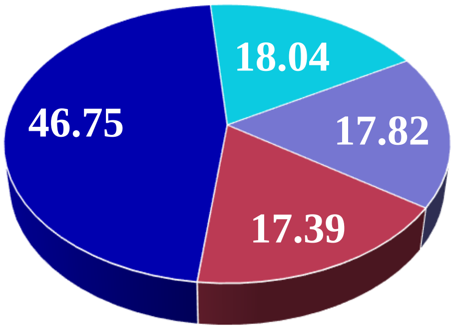




Studies of τ at STCF



- Precisely known kinematics of initial state
- Full reconstruction of signal side
- Neutrino in tag side is missing



Channel 1:

signal side $\tau \rightarrow \gamma\mu$

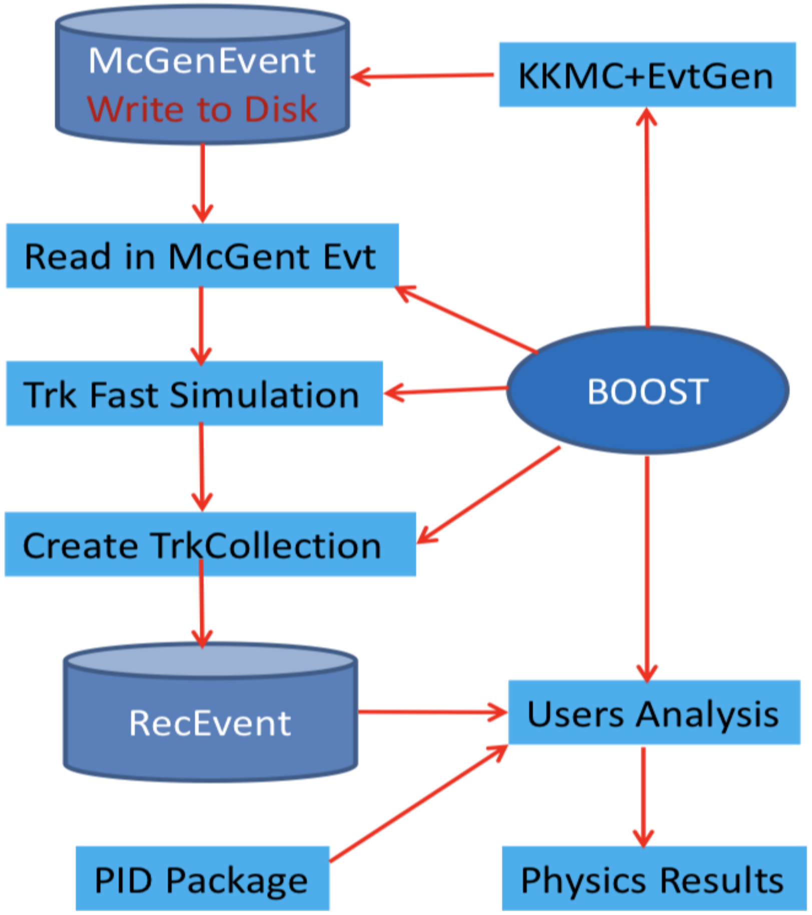
tag side $\tau \rightarrow e\upsilon\bar{\upsilon},\ \pi\upsilon,\ \pi\upsilon\pi^0$(total branching fraction $\approx$ 54%))

Channel 2:

signal side $\tau \rightarrow lll\ (e^+e^-e^-, \mu^+\mu^-\mu^-, e^+e^-\mu^-, \mu^+\mu^-e^-, \mu^+e^-e^-, e^+\mu^-\mu^-)$

tag side $\tau \rightarrow e\upsilon\bar{\upsilon},\ \mu\upsilon\bar{\upsilon},\ \pi\upsilon + n\pi^0$ (total branching fraction $\approx$ 82%)

Fast simulation tools

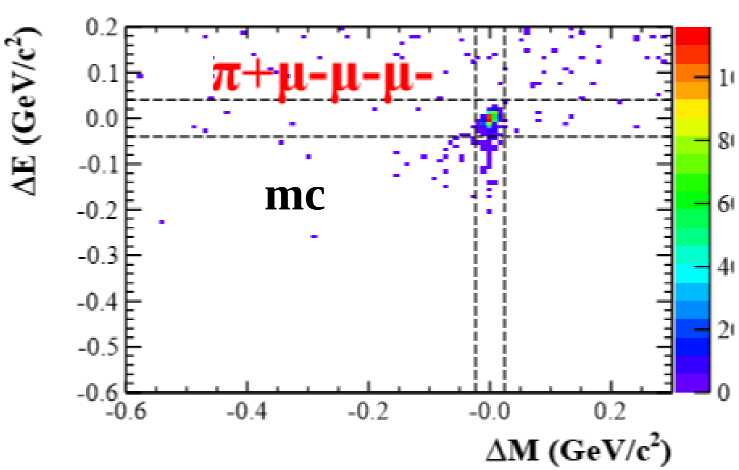


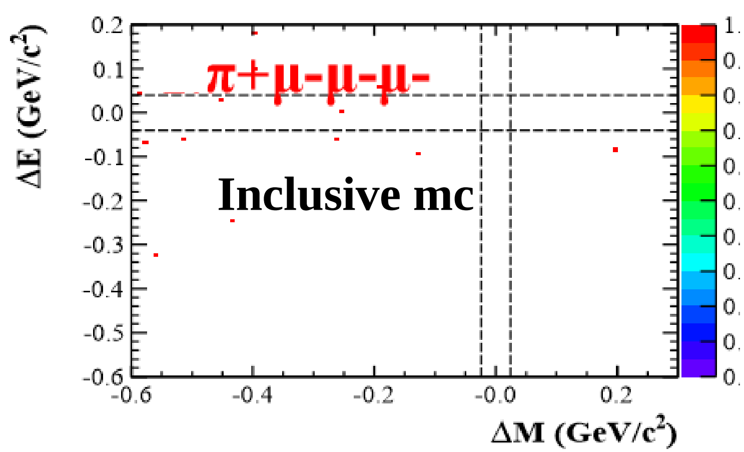
Studying the physics sensitivity, guiding the optimization of Detector design

- **Based on BESIII BOOST framework, same analysis process as BESIII jobs**
- **Implementing all the expected performance for the STCF detector.**
- **The input performances are flexible and adjustable for detector optimization**
- **Acceptable CPU and storage consumption**

Searches of $\tau \to 3l$

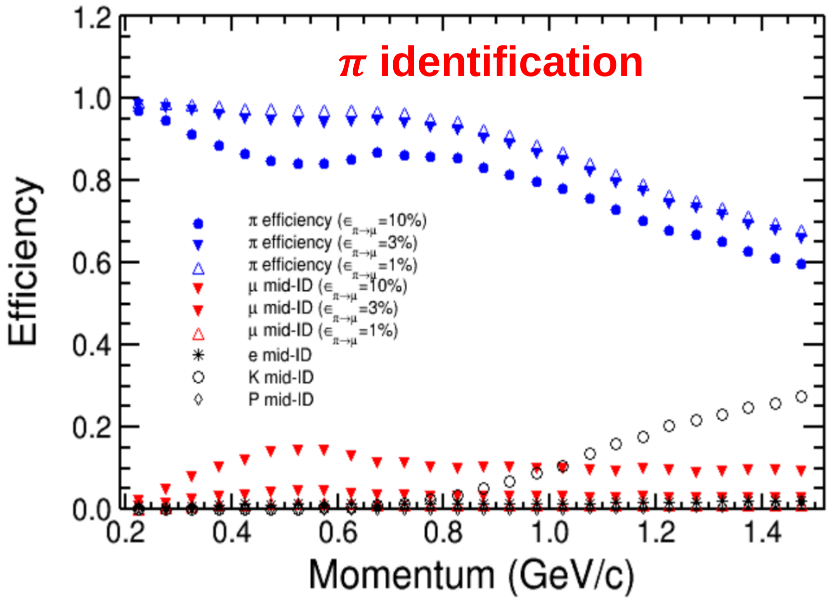
Tag side	Signal side
1-prong (pi/e/mu+neutrals+neutrinos), 82.62% branching fraction	Category 3-leptons into six types ($e^+e^-e^-$, $\mu^+\mu^-\mu^-$, $e^+e^-\mu^-$, $\mu^+\mu^-e^-$, $\mu^+e^-e^-$, $e^+\mu^-\mu^-$)
For hadronic tag mode, required missing mass $M^2_{\rm miss} < 0.2$ GeV^2	Veto gamma conversion, For e^+e^- pairs, $\|angle_{ee}\|>5^o$, $\|M_{ee}\|>0.05$GeV
For leptonic tag mode, $M^2_{\rm miss} < 2$ GeV^2	If more than one combination, select the one with minimum: $(M_{prong3}-M_\tau)^2/\sigma_{M\tau}+(E_{prong3}-E_\tau)^2/\sigma_{E\tau}$
Total Momentum of 1-prong side > 0.4 GeV/c	Using energy and mass constraint to select the signals, ΔE, ΔM
Angle between 1 prong and 3 prong <175^o	

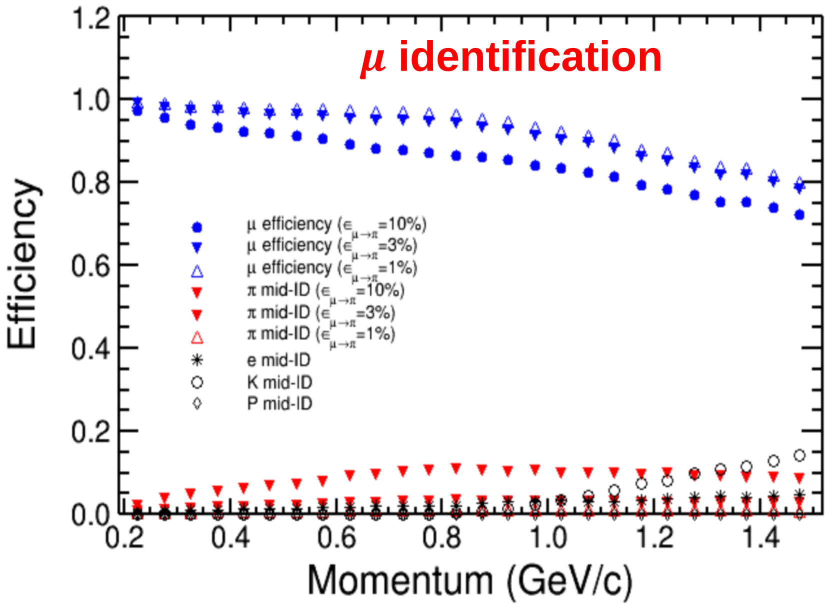




Searches of $\tau \to 3l$

- The PID efficiency in fast simulation is obtained from BESIII, using dE/dx and TOF information.(The mis-ID rate of π/μ can be as large as 30%).
- By scaling the π/μ mis-ID rate to 10%, 3%, 1% at 1GeV, different π/μ PID efficiencies are used.
- Following are the distributions of π/μ PID efficiencies and their mis-ID rates (the mis-ID rates to e, K, P are not changed in this analysis).

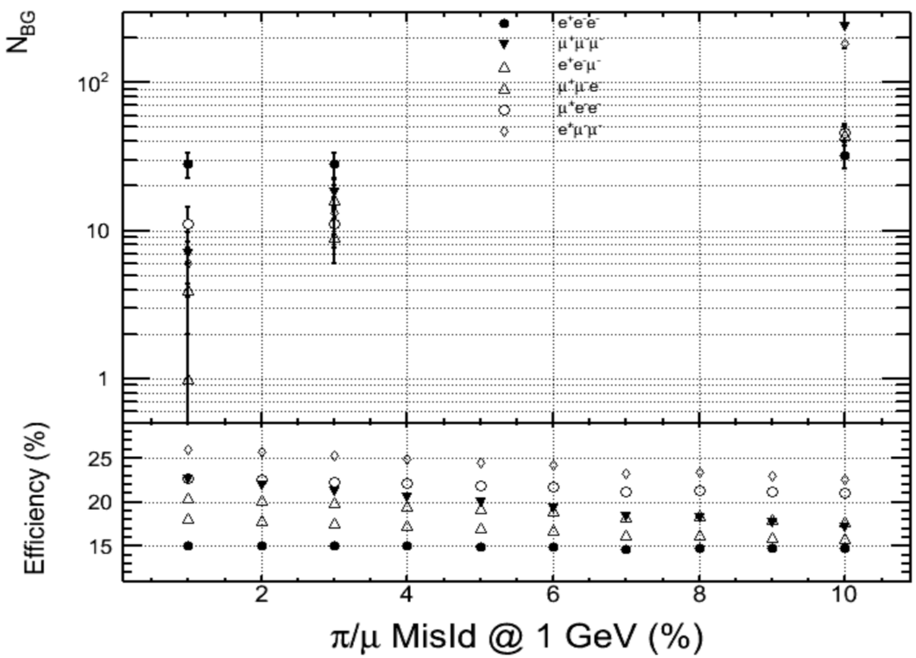




Searches of $\tau \to 3l$

中国科学技术大学 University of Science and Technology of China

- The number of survived events N_{BG} using 1 ab^{-1} inclusive data @ 4.26 GeV are obtained for the six decay modes of $\tau \to 3l$, with scaling π/μ mis-ID rate to 10%, 3%, 1%.
- The MC selection efficiency are also obtained by varying π/μ mis-ID rate from 10% to 1%.

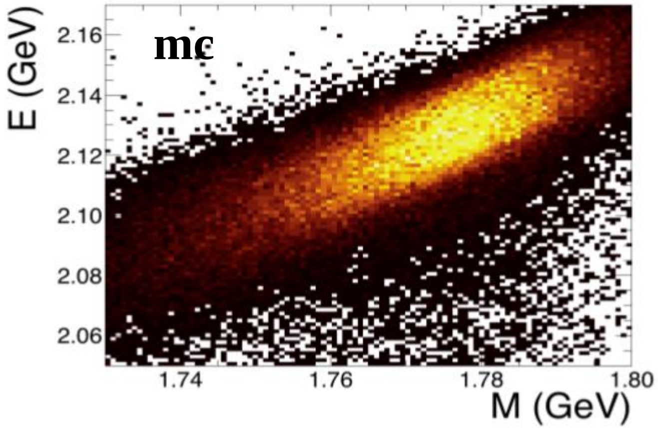


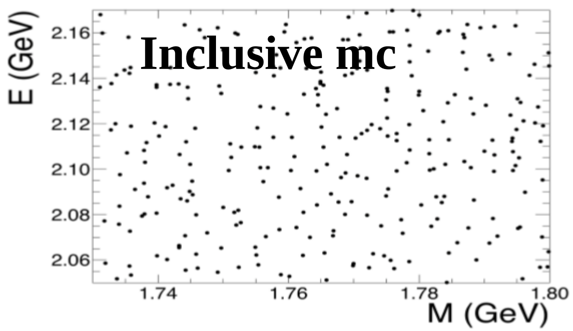
- At STCF, 3.5×10^9 tau pairs @ 4.26 GeV per year. If π/μ mis-ID rate is 1% at 1 GeV, the upper limit is predicted to be:

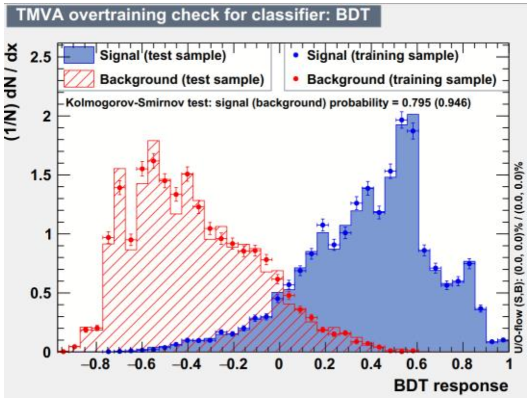
$$\mathcal{B}_{UL}^{90}(\tau \to 3l) < \frac{N_{UL}^{90}}{2\varepsilon N_{\tau\tau}} \sim 1.4 \times 10^{-9}$$

- If taken 10 years data, the best upper limit for $\tau \to 3l$ will be 1.4×10^{-10}
- Best efficiency $\tau \to \mu\mu\mu$ increased is 22.5%,

Searches of $\tau \to \gamma\mu$







MUC

	UL ($\times 10^8$)
MUC102, GammaP50%, GammaE80%	1.8
MUC101, GammaP50%, GammaE80%	1.5
MUC100, GammaP50%, GammaE80%	1.2

GammaP

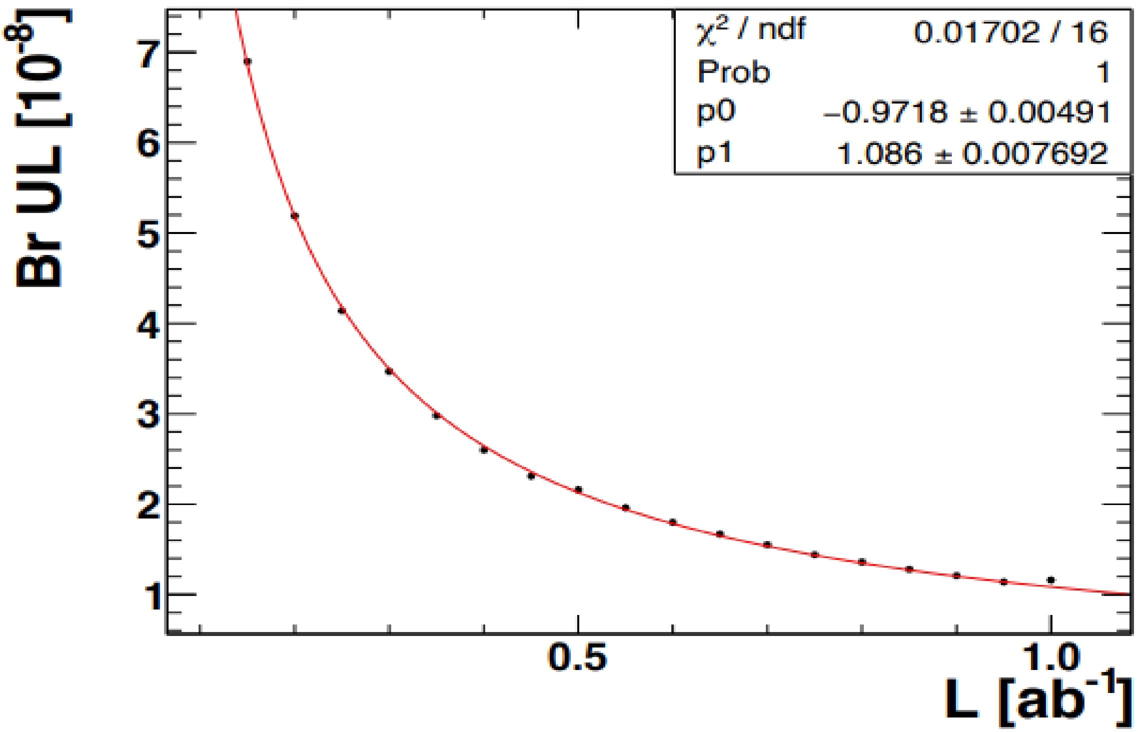
	UL ($\times 10^8$)
MUC102, GammaP50%, GammaE80%	1.8
MUC102, GammaP70%, GammaE80%	2.3
MUC102, GammaP100%, GammaE80%	2.5

GammaE

	UL ($\times 10^8$)
MUC102, GammaP50%, GammaE80%	1.8
MUC102, GammaP50%, GammaE90%	3.1
MUC102, GammaP50%, GammaE100%	5.1

- Optimization of STCF detector:
  - Photon position resolution better than **4 mm**
  - Good mu identification power, pi/mu mis-id better than **3%**

Searches of $\tau \to \gamma\mu$



extrapolate to $10ab^{-1}$: 1.2×10^{-9}

Summary and Prospect

中国科学技术大学
University of Science and Technology of China

- At STCF, with $1ab^{-1}$ luminosity at 4.26 GeV (3.5×10^9 τ pair), the expected results of cLFV are:

$$\mathcal{B}_{UL}^{90}(\tau \to \mu\mu\mu) < \frac{N_{UL}^{90}}{2\varepsilon N_{\tau\tau}} \sim 1.4 \times 10^{-9}$$

$$\mathcal{B}_{UL}^{90}(\tau \to \gamma\mu) < \frac{N_{UL}^{90}}{2\varepsilon N_{\tau\tau}} \sim 1.2 \times 10^{-8}$$

Timeline for STCF

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030-2040	2041-2042
Form Group	■	■	■	■										
CDR	■	■	■	■										
TDR	■	■	■	■	■	■	■							
Construction							■	■	■	■	■	■		
In operation													■	
Upgrade														■

Thanks!

谢谢！