Search for the CLFV Process $J/\psi \to \gamma l\tau(l = e, \mu)$ at STCF

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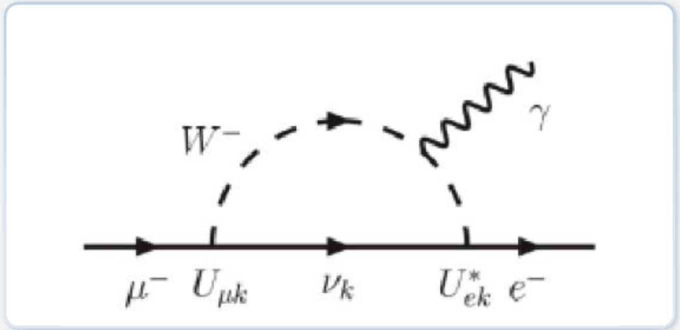
Motivation

- The Standard Model(SM)：
  - The Standerd Model successfully describes fundamental paricles and their interactions, including the mass generation mechanism. Quarks undergo flavor changes via the CKM matrix, while lepton flavor is conserved as long as neutrinos are massless.
- Lepton Flavor Violation: Discovery of neutrino oscillations confirmed that neutrinos have mass, implying lepton flavor violation in the neutral-lepton sector.
- CLFV: can occur in extended SM frameworks, such as those including right-handed neutrinos.
- Possible New Physics:
  - The CLFV processes suffer strong suppression of FCNC by GIM mechanism, e.g., the prediction of the branching fraction of $\mu \rightarrow e\gamma$ is less than 10^{-54}, which is way far beyond the reach of current experimental sensitivity.
  - Any observation of CLFV at levels much higher than this would be a clear evidence for new physics.



Motivation

- The effective Largrangian of new physics models can be expressed as the sum of a diople term, four-fermionic interactions and a gluonic interaction part.
- The dipole part has been extremely well constrained in purely leptonic CLFV decays of the type $l' \rightarrow l\gamma$.
- Vector, axial-vector, and tensor operators in four-fermion interactions enable CLFV transitions. Two-body vector meson CLFV decays allow one to probe the vector and tensor operators effectively. And the radiative CLFV decays of quarkonium states, such as $V \rightarrow \gamma ll'(l \neq l'$ and $V = \omega, \phi, J/\psi, \psi(2S))$, provide valuable insights into CLFV interactions mediated by resonant scalar, pseudoscalar and axial-vector mesons.
- However, only $\Upsilon(\mathrm{nS}) \rightarrow \gamma ll'$ have been studied in radiative CLFV searches, experimental results for radiative CLFV decays $\omega, \phi, J/\psi, \psi(2S)$, B and D mesons remain unexplored.
- By Studying the radiative CLFV decays of $J/\psi \rightarrow \gamma ll'$, one can also explore the posssibility of two body CLFV decays of pseudoscalar mesons $p \rightarrow ll'(p = \eta, \eta', \eta_c)$, where the pseudoscalar states can be produced via $J/\psi \rightarrow \gamma p$.
- In this report we focus on the radiative CLFV decay of $J/\psi \rightarrow \gamma l\tau$.

$J/\psi \to \gamma l \tau$ in STCF

STCF is designed to collect data with a statistics 100 times greater than existing facilities in China, covering a center-of-mass energy range of 2 to 7 GeV. The table below showes the expected sensitivity for radiative CLFV decays of charmonium mesons and D^0 mesons at BESIII and STCF.

衰变模式	预期灵敏度	
	at BESIII	at STCF
$J/\psi \to \gamma l l'$	$(1-3)\times 10^{-8}$	$(1-3)\times 10^{-9}$
$\chi_{c_J} \to l l'$	$(1-3)\times 10^{-7}$	$(1-3)\times 10^{-8}$
$\eta_c \to l l'$	$(2-5)\times 10^{-7}$	$(2-5)\times 10^{-8}$
$D^0 \to \gamma e \mu$	$(5-10)\times 10^{-7}$	$(5-10)\times 10^{-8}$

OSCAR

- We plan to determine the expected sensitivity of $J/\psi \to \gamma l \tau$ using Full Chain MC simulations with OSCAR. This study will also provide an opportunity to optimize the detector design, enhancing the capability to observe CLFV decays on STCF.

EvtGen

- example: $J/\psi \to \gamma e \tau$ decay card

```
Decay J/psi
1.000       gamma e+ tau-               PHSP;
Enddecay

Decay tau-
1.000       mu- anti-nu_mu nu_tau       PHOTOS TAULNUNU;
Enddecay

End
```

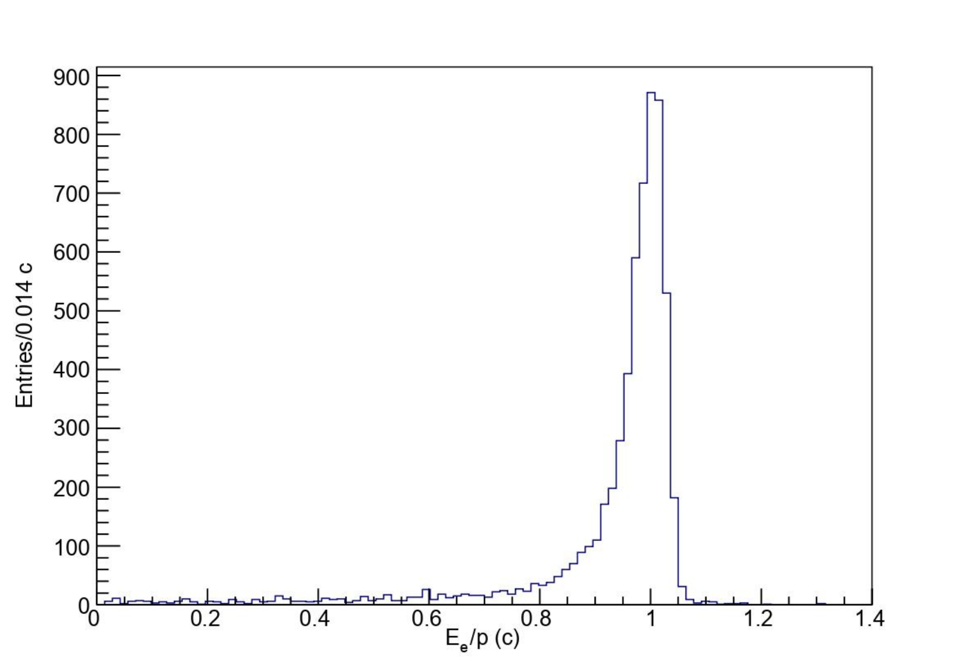
- 10k events generated using the default scripts under oscar2.6.2_pre2

General Event Selection

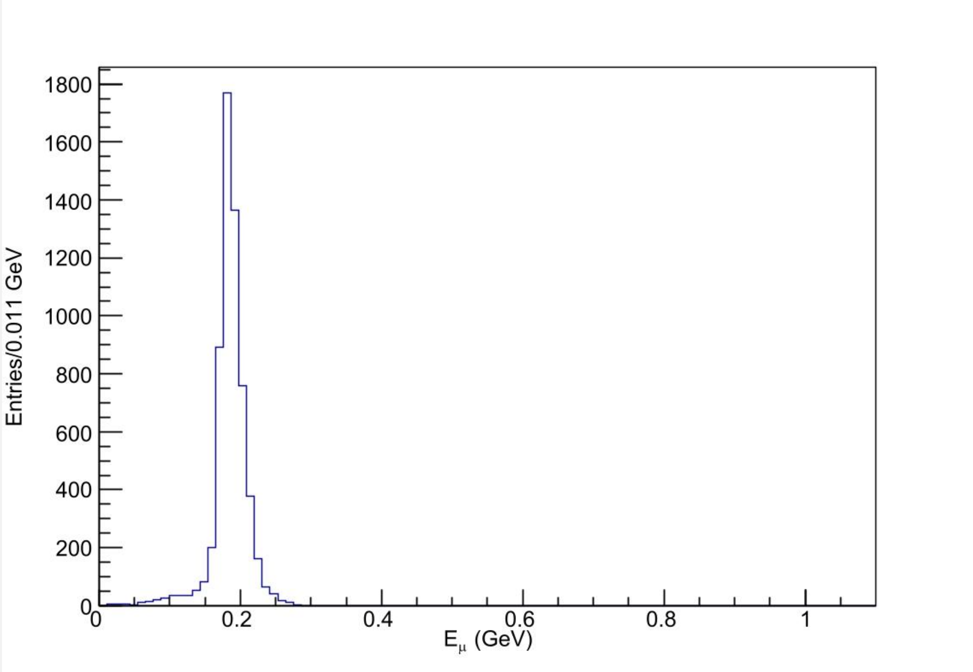
- Charged tracks:
  - $|V_r| < 1cm$，$|V_z| < 10cm$，$|\cos\theta| < 0.93$
  - $N_e = 1$ && $N_\mu = 1$
  - 2 charged tracks in total
- Photon:
  - barrel region（$|\cos\theta_\gamma| < 0.8325$）： $E_\gamma > 25\mathrm{MeV}$
  - endcap（$0.8325 < |\cos\theta_\gamma| < 0.9445$）： $E_\gamma > 50\mathrm{MeV}$
  - The angle between the photon and the nearest extrapolated track in the EMC: dang > 10 degrees
  - $N_\gamma \geq 1$
- Vertex fit for the charged tracks
- Best photon candidate: $m_{rec}^{\gamma l}$ closest to nominal tau mass
- for this selected photon candidate: $|\cos\theta_\gamma| < 0.8325$
- missing neutrino-pair: $|\cos\theta_{rec}^{\gamma e\mu}| < 0.8325$
- we use GlobalPID based on ML(XGBoost) before the charged track selection

Particle Identification

- for electrons: $0.8 < E_e/p < 1.1\ c$

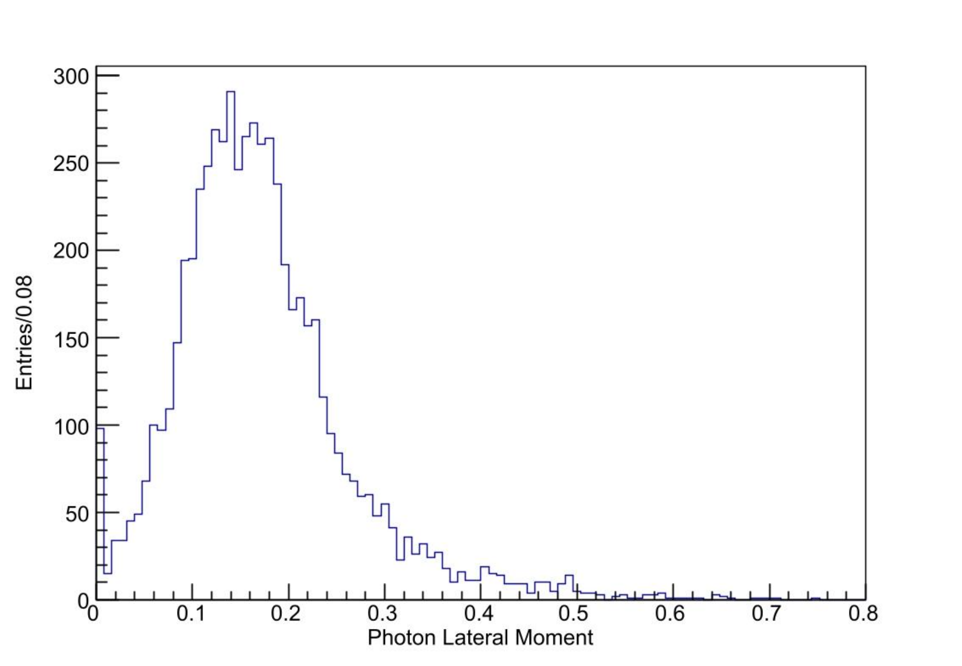


- for muons: $0.1 < E_\mu < 0.3\text{GeV}$

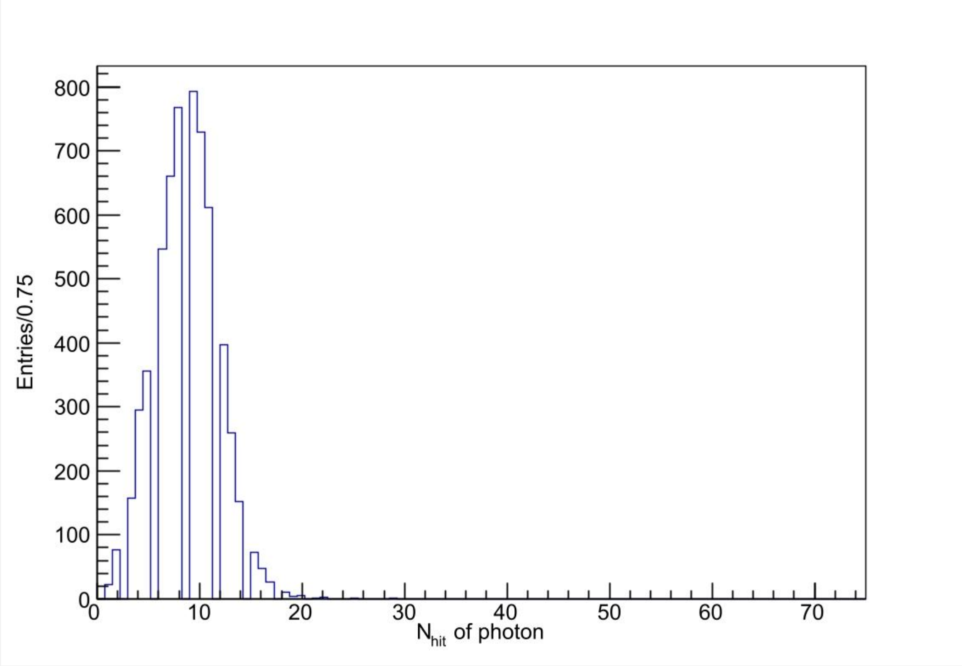


Seperation between good photons and neutral hadrons

- lateral moment: [0.04, 0.4]
- reject backgrounds from $J/\psi \to n\bar{n}\pi^+\pi^-$

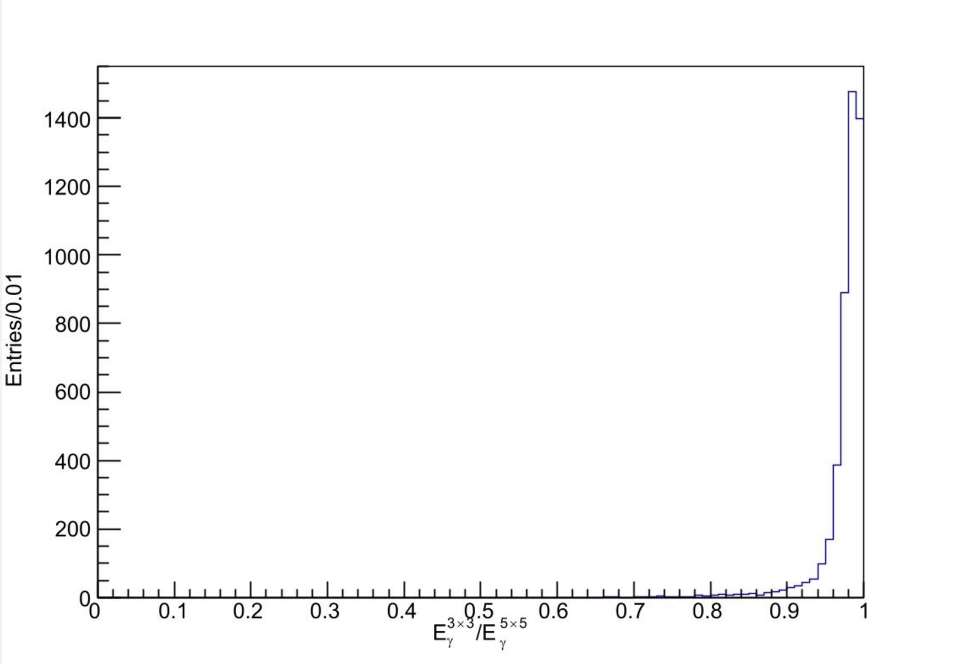


- number of hits < 35

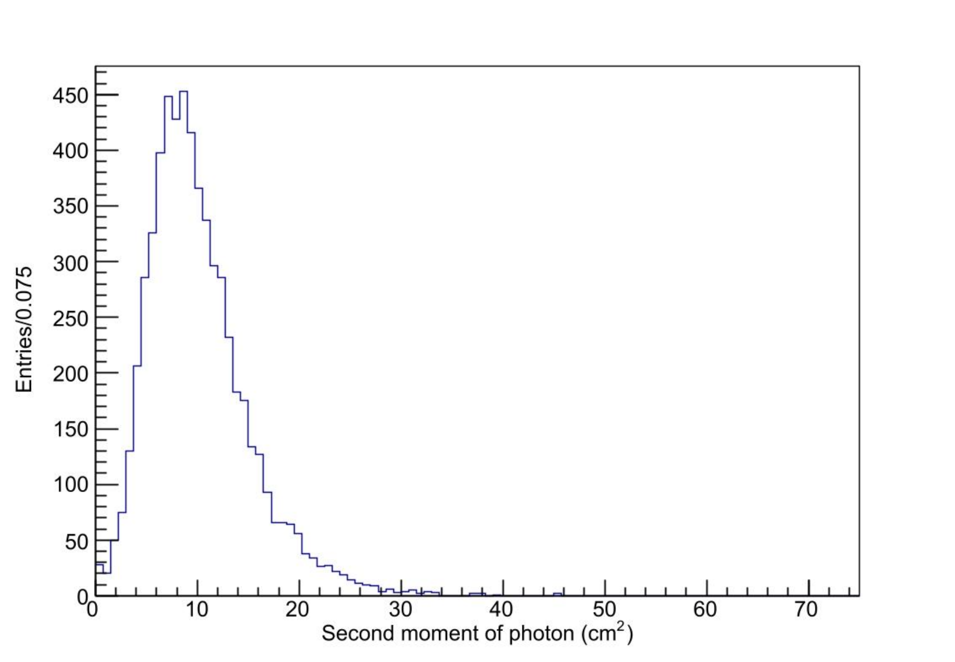


Seperation between good photons and neutral hadrons

- the enegy ratio of 3x3 to 5x5 ECAL crystals > 0.9

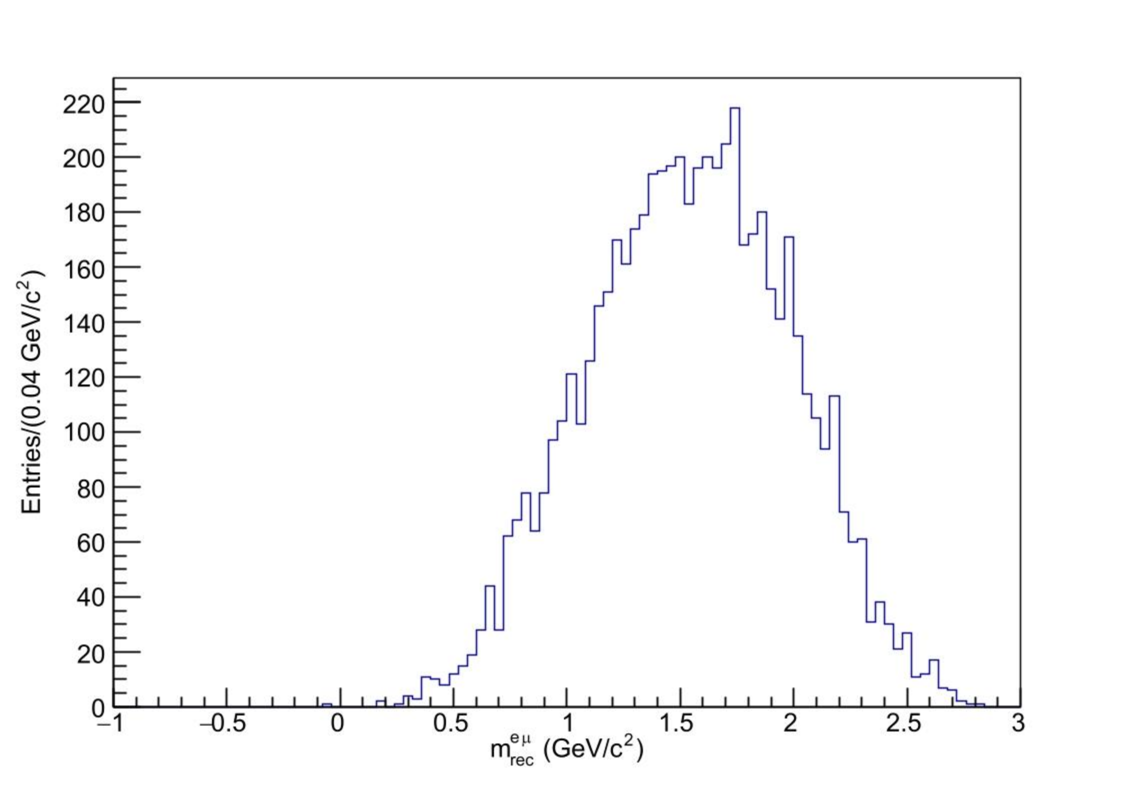


- second-moment $< \ 25\ cm^2$



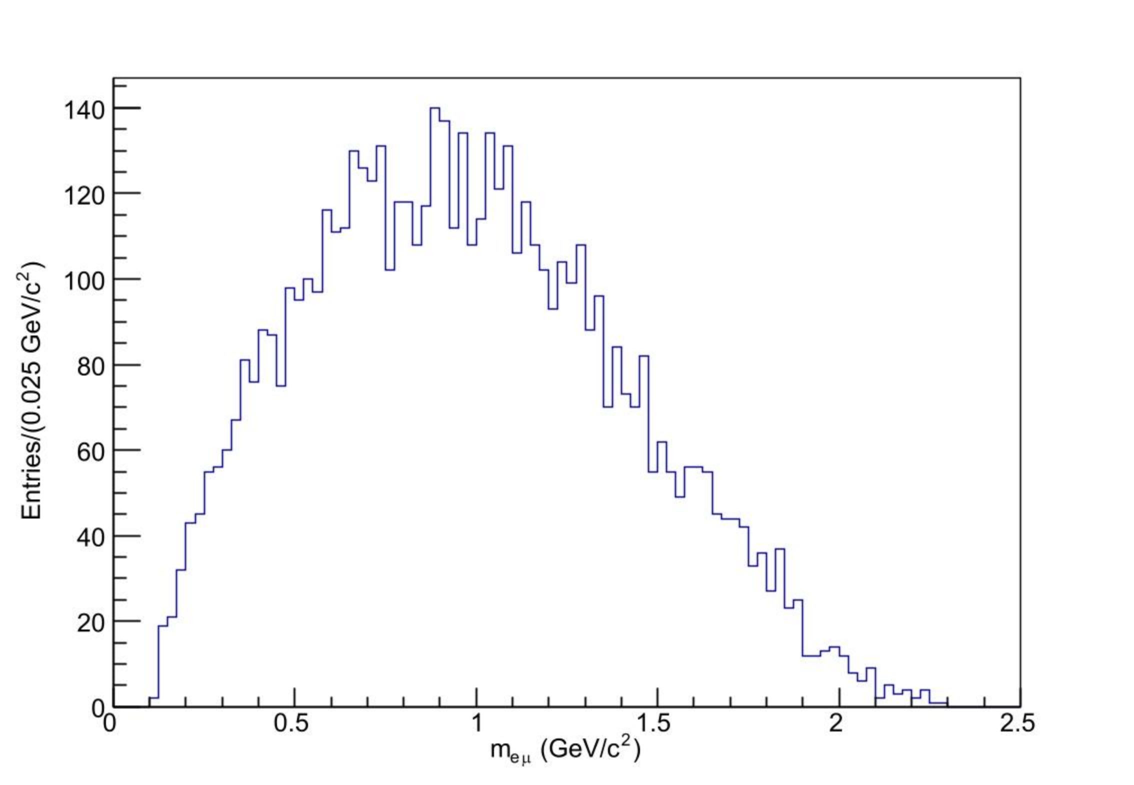
Background suppression from radiative $J/\psi \to \gamma X$

- to suppress $J/\psi \to \gamma hh (h = e, \mu, \pi)$, we require $m_{rec}^{e\mu} > 0.5\ \mathrm{GeV}/c^2$



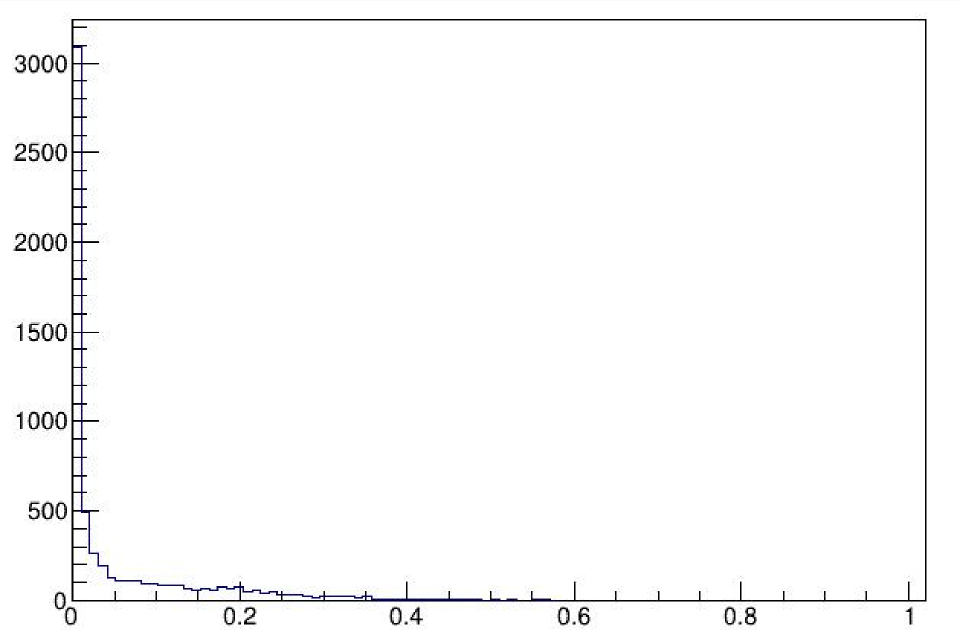
Veto of $K_S^0 \to \pi^+\pi^-$ background

- $0.428 < m_{e\mu} < 0.453\ \mathrm{GeV}/c^2$



Background rejection from extra photons

- $E_\gamma^{extra} < 0.2\text{GeV}$



- here E_γ^{extra} is the sum of the energies of all extra photons not used for $J/\psi \to \gamma l\tau$ reconstruction.

Efficiency

- results on BESIII($J/\psi \to \gamma e \tau$ signal MC)

Selection criteria	$J/\psi \to \gamma e \tau$
$N_{\text{Generated}}$	63500
$N_{\text{CT}} = 2$	52222
$N_\gamma \geq 1$	45368
Pass Pid:	43834
$e^\pm \mu^\mp$ vertex fit:	43734
Pre-selection cuts	38369
E_e/p cut	36468
E_μ cut	35869
$\lvert\Delta t_\mu^{TOF}\rvert < 0.26$ ns	34134
$\lvert\Delta t_e^{TOF}\rvert < 0.26$ ns	32836
π^0 veto	32161
η veto	32022
$1.6 \leq m_{rec}^{\gamma l} \leq 2$ GeV	30413
Depth in MuC	20875
$\lvert\cos\theta_\gamma\rvert < 0.8$	19360
E_γ^{Extra}	18936
Lateral moment	18276
$E_\gamma^{3\times3}/E_\gamma^{5\times5}$	18087
N_γ^{hit}	17897
γ second moment	17730
$\lvert\cos\theta_{rec}^{\gamma e\mu}\rvert < 0.8$	17566
K_S^0 vet0	14744
$m_{rec}^{e\mu}$ cut	14505
$\lvert\chi_{dE/dx}^e\rvert < 2.5$ cut	14436
Signal selection efficiency (%)	22.73

- results on STCF($J/\psi \to \gamma e \tau$ signal MC)

Selection criteria	$J/\psi \to \gamma e \tau$
$N_{Generated}$	10000
Good Tracks	6412
Good Photons	5993
Vertex Fit	5993
E_e/p cut	5378
E_μ cut	5294
$1.6 < m_{rec}^{\gamma l} < 2$ GeV	5030
$\lvert\cos\theta_\gamma\rvert < 0.8325$	4518
E_γ^{extra}	4190
Lateral moment	3922
N_γ^{hit}	3922
$E_\gamma^{3\times3}/E_\gamma^{5\times5}$	3882
Second moment	3871
$\lvert\cos\theta_{rec}^{\gamma e\mu}\rvert < 0.8325$	3248
K_S^0 veto	3200
$m_{rec}^{e\mu}$ cut	3173

Next Step

- Update to the newest OSCAR version
- Optimize event selection using inclusive J/ψ MC samples
- Achieve the veto of π^0 and η candidates
- Check variables like Δt^{TOF} and $\chi^e_{dE/dx}$ at BESIII
- Though GloblePID uses MUD information to identify muon, we will also check MUD variables to see if we can optimize muon identification

THANK YOU