τ physics at Super-tau-Charm factory

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1. τ Branching ratio measurement at threshold
   1) Statistic estimation
   2) Possible optimization
2. CPV in tau decays
3. cLFV in tau decays

Super-τ-C Luminosity : 10^{35} cm^{-2} s^{-1} ($100nb^{-1}$ s^{-1})

One running year (180days, 15.552Ms)

Cross section@ τ-threshold : 0.1nb

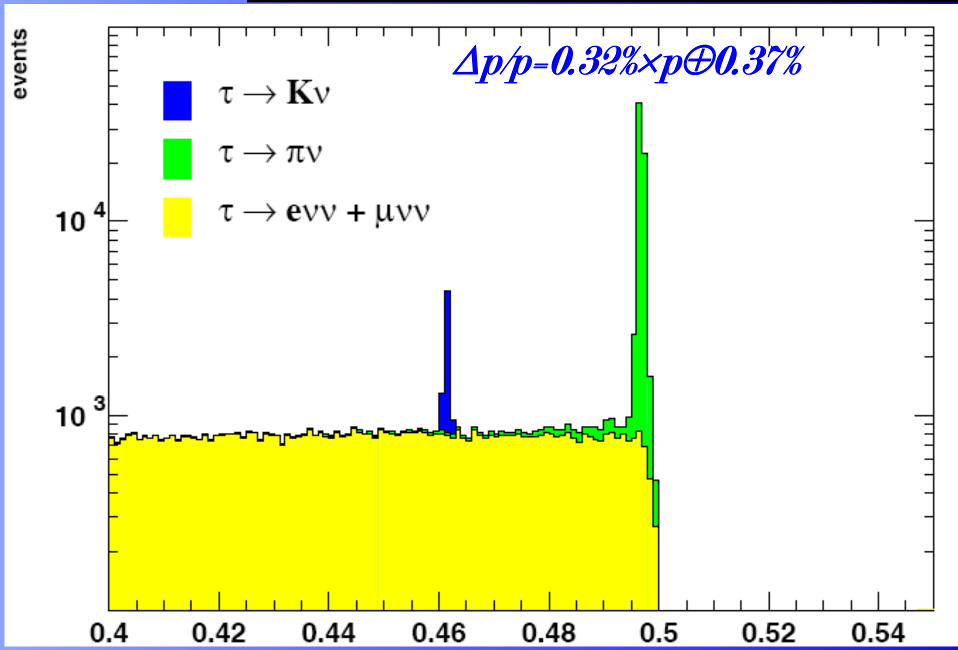
Data taking efficiency : 80%

Final state	ε (from BESIII)	Br.	Num. Evt.	Sta. Re. Error	PDG
ee	17%	0.1783*0.1783	8.2 G	1.1×10^{-5}	$\tau^-\rightarrow e^-\nu\nu$ 2.24×10^{-3}
eμ	22%	0.1783*0.1741	10.9 G	9.6×10^{-6}	$\tau^+\rightarrow \mu^+\nu\nu$ 2.29×10^{-3}
eh	32%	0.1783*0.1153	10.2 G	9.9×10^{-6}	$\tau^\pm\rightarrow\pi^\pm\nu$ 5.54×10^{-3}

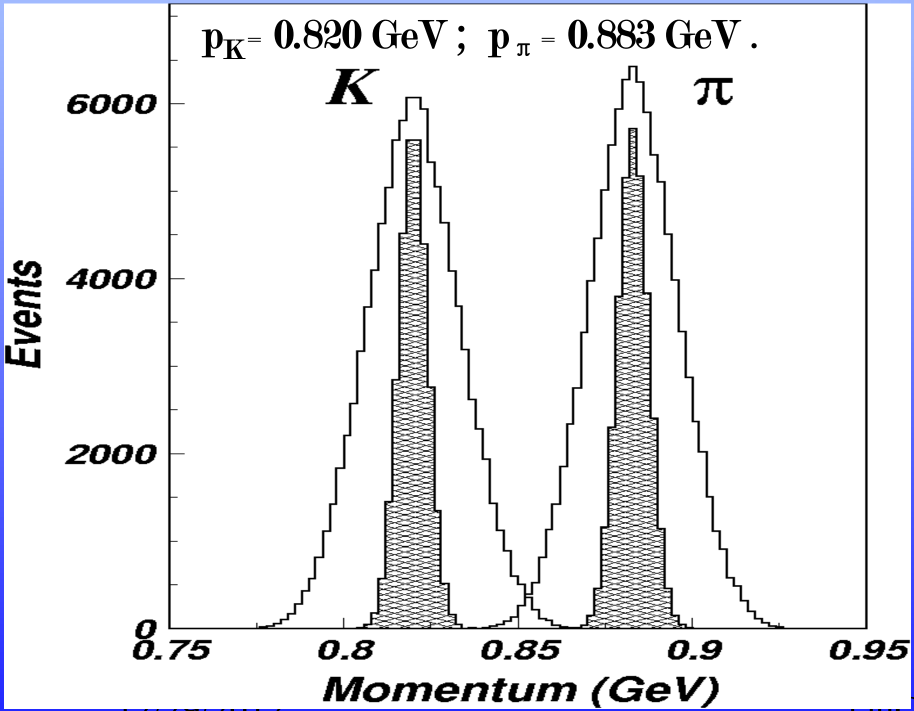
(h: hadron, π&K)

- 能散效应(一直被忽略)
- τ轻子对衰变到 ππ / KK 末态的模拟研究

τ轻子对→ ππ /KK

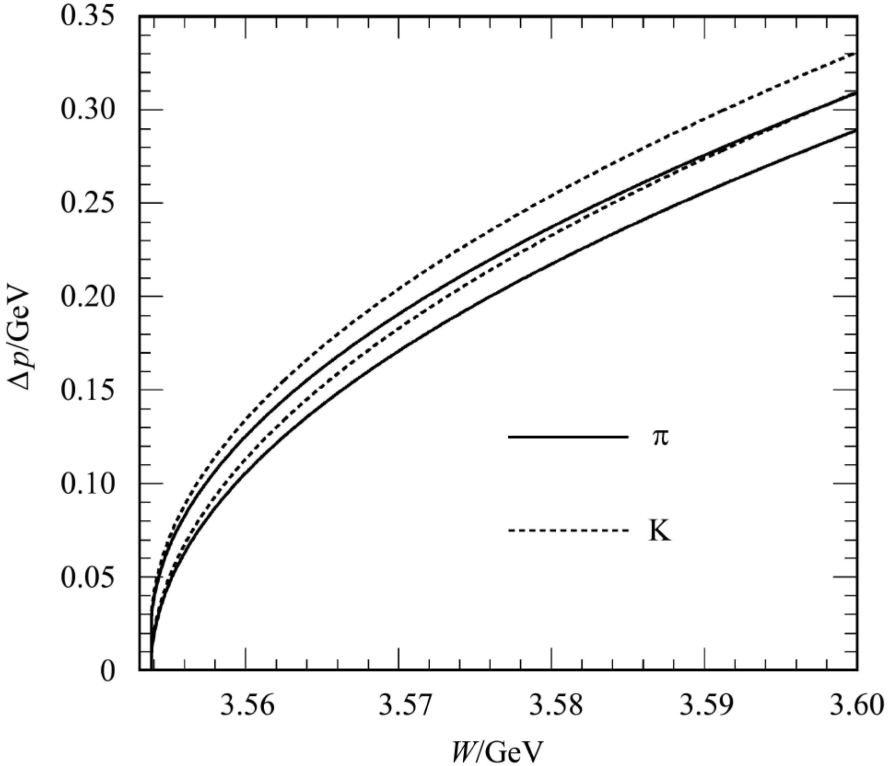


$E_{threshold}$=3.554 GeV ; τ-轻子对静止



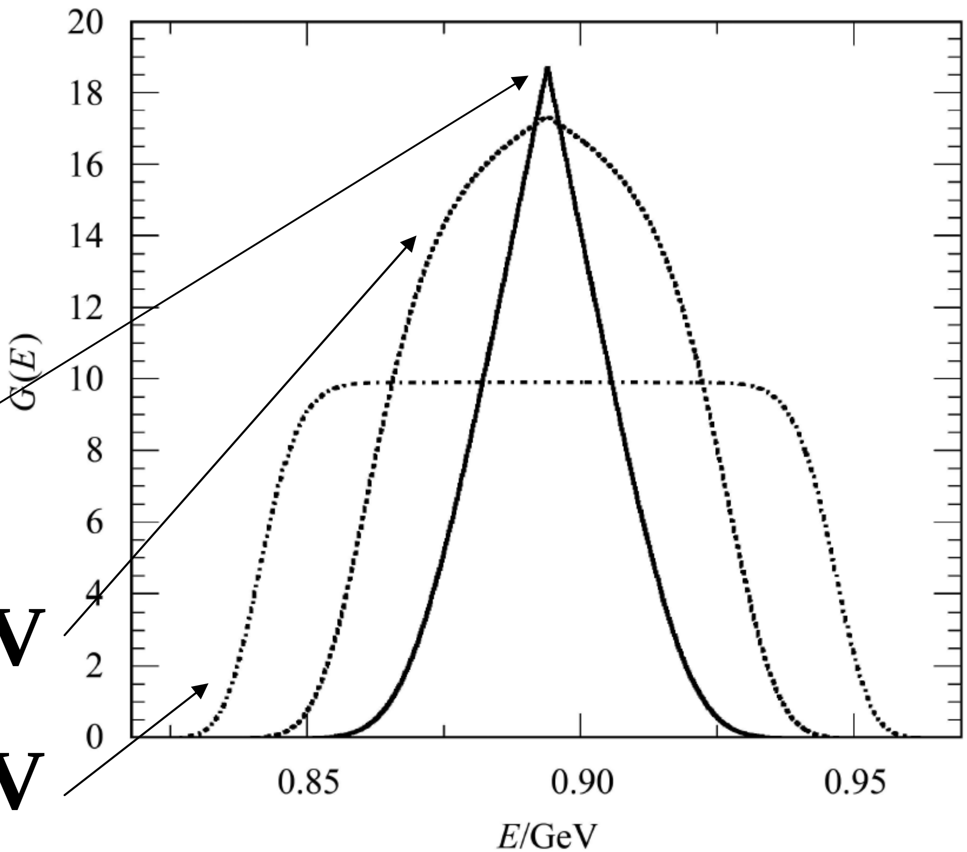
- ✓ 阈值处截面小,动量展宽小
- ✓ 远离阈值,动量展宽大

能散对于粒子单能能谱的影响



Kinematics effect for moving particle

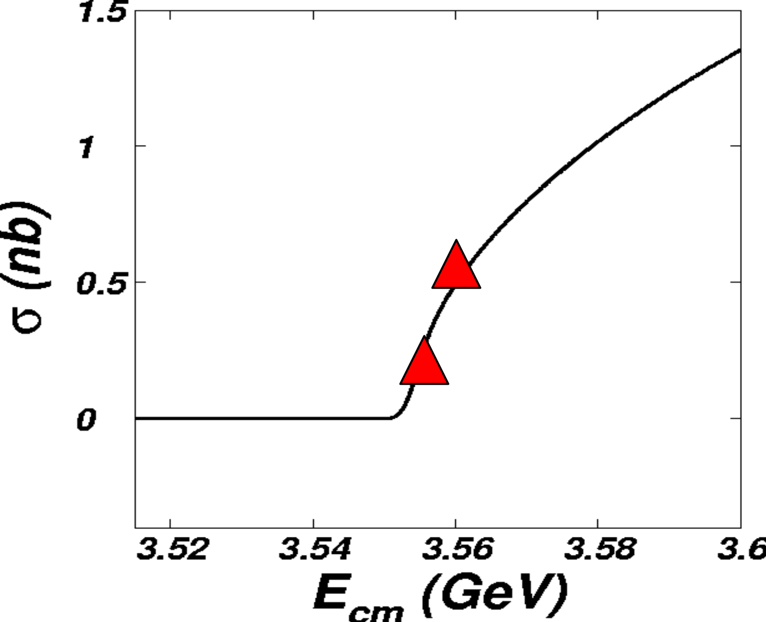
Energy spread Δ=1.2MeV



$W=2m_\tau=3553.64$MeV

$W=2m_\tau + 2\Delta = 3556.04$MeV

$W=2m_\tau + 5\Delta = 3559.64$MeV



Optimization is needed to fix two points, one at threshold, the other away from it, and determine their position and luminosity ratio in order to obtain more efficient measurement results

Rare and Forbidden decays

New phenomena & new physics

***Rare decay* : low level, vanish at the perfect of some approximate symmetry**

***Forbidden decay* : violate conservation law**

B(τ →F_1) First class current: F_1 J^{PC}= $\mathbf{0}^{++}$, $\mathbf{0}^{--}$, $\mathbf{1}^{+-}$, $\mathbf{1}^{-+}$

B(τ →F_2) Second class current: F_2 J^{PC}= $\mathbf{0}^{+-}$, $\mathbf{0}^{-+}$, $\mathbf{1}^{++}$, $\mathbf{1}^{--}$

$$B(\tau \to F_2) \propto \Delta m \xrightarrow{\Delta m \to 0} 0, \ (\Delta m = m_d - m_u)$$

Δm=0: perfect isospin symmetry

$$\tau \to a_0(980)\nu_\tau, \ a_0(980) \to \eta\pi \quad B(\tau \to \eta\pi\nu_\tau) < 1.4 \times 10^{-4}$$

CLEO:PRL76(1996)4119

Rare decay: low level, vanish at the perfect of some approximate symmetry

Forbidden decay: violate conservation law

- ✓能动量守恒
- ✓角动量守恒
- ✓总电荷守恒
- ✓轻子数守恒
- ✓…

衰变过程：	τ^-	$\rightarrow$	ν_τ	+	e^-	+	$\bar{\nu}_e$
电子数：	0	=	0	+	1	+	−1
Muon-子数：	0	=	0	+	0	+	0
Tau-子数：	1	=	1	+	0	+	0

允许衰变过程： $\tau^- \rightarrow \nu_\tau + \mu^- + \bar{\nu}_\mu$; $\tau^- \rightarrow \nu_\tau + e^- + \bar{\nu}_e$

禁止衰变过程： $\tau^- \rightarrow \gamma + (\mu / e)^-; \tau^- \rightarrow \mu^- + \mu^+ + \mu^- \ldots$

实验寻找“禁止”过程存在的证据是探索新物理的一种方式。

Symmetry and Conservation law

But not symmetry for lepton number conservation law

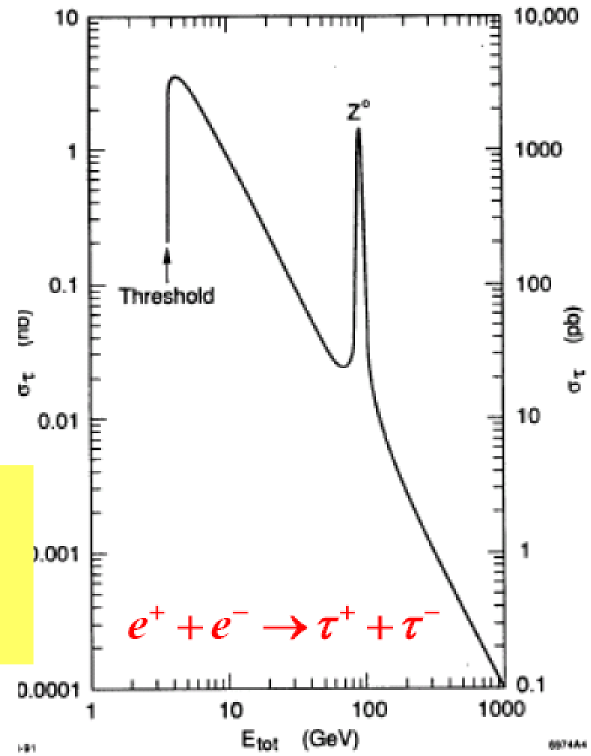
LEPTON FLAVOUR VIOLATION

90% CL Upper Limits on $Br(l^- \to X^-)$ [BABAR / BELLE]

Decay	U.L.	Decay	U.L.	Decay	U.L.
$\mu^- \to e^-\gamma$	$1.2 \cdot 10^{-11}$	$\mu^- \to e^-e^+e^-$	$1.0 \cdot 10^{-12}$	$\mu^- \to e^-\gamma\gamma$	$7.2 \cdot 10^{-11}$
$\tau^- \to e^-\gamma$	$1.1 \cdot 10^{-7}$	$\tau^- \to e^-e^+e^-$	$2.0 \cdot 10^{-7}$	$\tau^- \to e^-e^+\mu^-$	$1.9 \cdot 10^{-7}$
$\tau^- \to \mu^-\gamma$	$6.8 \cdot 10^{-8}$	$\tau^- \to e^-\mu^+\mu^-$	$2.0 \cdot 10^{-7}$	$\tau^- \to \mu^-e^+\mu^-$	$1.3 \cdot 10^{-7}$
$\tau^- \to e^-e^-\mu^+$	$1.1 \cdot 10^{-7}$	$\tau^- \to \mu^-\mu^+\mu^-$	$1.9 \cdot 10^{-7}$	$\tau^- \to e^-\pi^0$	$1.9 \cdot 10^{-7}$
$\tau^- \to \mu^-\pi^0$	$4.1 \cdot 10^{-7}$	$\tau^- \to e^-\eta'$	$10 \cdot 10^{-7}$	$\tau^- \to \mu^-\eta'$	$4.7 \cdot 10^{-7}$
$\tau^- \to e^-\eta$	$2.3 \cdot 10^{-7}$	$\tau^- \to \mu^-\eta$	$1.5 \cdot 10^{-7}$	$\tau^- \to e^-K^*$	$3.0 \cdot 10^{-7}$
$\tau^- \to e^-K_S$	$5.6 \cdot 10^{-8}$	$\tau^- \to \mu^-K_S$	$4.9 \cdot 10^{-8}$	$\tau^- \to \mu^-\rho^0$	$2.0 \cdot 10^{-7}$
$\tau^- \to e^-K^+K^-$	$1.4 \cdot 10^{-7}$	$\tau^- \to e^-K^+\pi^-$	$1.6 \cdot 10^{-7}$	$\tau^- \to e^-\pi^+K^-$	$3.2 \cdot 10^{-7}$
$\tau^- \to \mu^-K^+K^-$	$2.5 \cdot 10^{-7}$	$\tau^- \to \mu^-K^+\pi^-$	$3.2 \cdot 10^{-7}$	$\tau^- \to \mu^-\pi^+K^-$	$2.6 \cdot 10^{-7}$
$\tau^- \to e^-\pi^+\pi^-$	$1.2 \cdot 10^{-7}$	$\tau^- \to \mu^-\pi^+\pi^-$	$2.9 \cdot 10^{-7}$	$\tau^- \to \Lambda\pi^-$	$0.7 \cdot 10^{-7}$
$\tau^- \to e^+K^-K^-$	$1.5 \cdot 10^{-7}$	$\tau^- \to e^+K^-\pi^-$	$1.8 \cdot 10^{-7}$	$\tau^- \to e^+\pi^-\pi^-$	$2.0 \cdot 10^{-7}$
$\tau^- \to \mu^+K^-K^-$	$4.4 \cdot 10^{-7}$	$\tau^- \to \mu^+K^-\pi^-$	$2.2 \cdot 10^{-7}$	$\tau^- \to \mu^+\pi^-\pi^-$	$0.7 \cdot 10^{-7}$

Cross section of τ and estimated luminosities of different experiments

The largest cross section is at tau-Charm region, the next is at Z^0



Super B(elle) Factory with $L=10^{36}$ /cm²/s and σ = 1 nb

$\sim 10^{10}$ τ pairs per year ($\int$ L=50/ab, 2016-2022)

Super τ-Charm Factory at 10^{35} /cm²/s

$\sim 10^{8}$ τ pair /year at threshold (σ = 0.1 nb)

$\sim 3.5 \times 10^{9}$ /year at 4.25 GeV (σ_{peak} = 3.5 nb)

Giga-Z will have the same statistics as that at super-B factory.

Tau at different energies

- **At and near threshold (3.55-3.65 GeV): KEDR, BESIII, SτCF**
  - Precise mass measurement
  - Powerful kinematic constraints in decays of τ produced at rest
  - Non-τ backgrounds well known from running just below the threshold
  - very small radiative corrections
  - Generally, very low systematic errors, but low cross-sections
- **At a few GeV (4.10- 4.25 GeV): BESIII, SτCF**
  - Increased cross-sections, for τCF competitive with SBF for statistics
  - Low systematic errors: Leptonic branching fractions
  - Polarized beams for CP violation in decays; LFV in decays
- **At Upsilon(4S): BABAR, Belle, Super-B factories**
  - High luminosity and high statistics
  - Generally, large background for hadronic decays
- **At Z- Giga Z factory: ILC**
  - Potentially very high statistics
  - Conditions as LEP: relatively low backgrounds and low systematic errors
  - Precise life time measurement from Lorenzt boost
  - Polarized beams, SM coupling…. the LEP programme with much high statistics
- **A few hundred GeV (200-500 GeV): ILC**
  - As at Giga Z but much lower rates
  - Sensitive to New physics couplings in $\tau^+\tau^-$ productions

Li Haibo, 2012, Lanzhou

Charged lepton flavor violation (cLFV)

- cLFV is negligible in the SM
- τ, the heaviest lepton, is the most suitable lepton to study the cLFV effect
- Golden mode
  - $\tau \to \mu \gamma$
  - Current limit: $\sim 3 \times 10^{-8}$ by BELLE
  - Super-B will be limited by the ISR background
  - Sensitivity at 4.25GeV $\sim 10^{-9}$?
- Super tauCharm factory may not take advantage for $\tau \to$ eee or $\mu\mu\mu$

CP violation in τ decays

- May caused by interference between W and scalar boson.
- Polarized beam needed: τ τ decay angle distribution [Y.S. Tsai, PRD 55, 3172, (1955)]
  - $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$, sensitivity 10^{-4}? .
  - M(τ τ) near to the threshold would be almost s-save and keep the polarization better
  - FOM = L $\times$ ω_z $\times$ total cross section
  - BESIII @ 4.25 (10^{33}/cm^2/s) FOM=1
  - STCF @ threshold (10^{35}/cm^2/s) FOM=3
  - STCF @ 4.25 (10^{35}/cm^2/s) FOM=100
  - Super-B @ Y(4S) (10^{36}/cm^2/s) FOM=65
  - Giga-Z @ Z^0 FOM small O(1/E^2)