国家重点研发项目“粲强子衰变和标准模型的精确检验”2025年夏季年会

Study of $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ and $\tau^+ \to K^+\pi^0\overline{\nu}_\tau$

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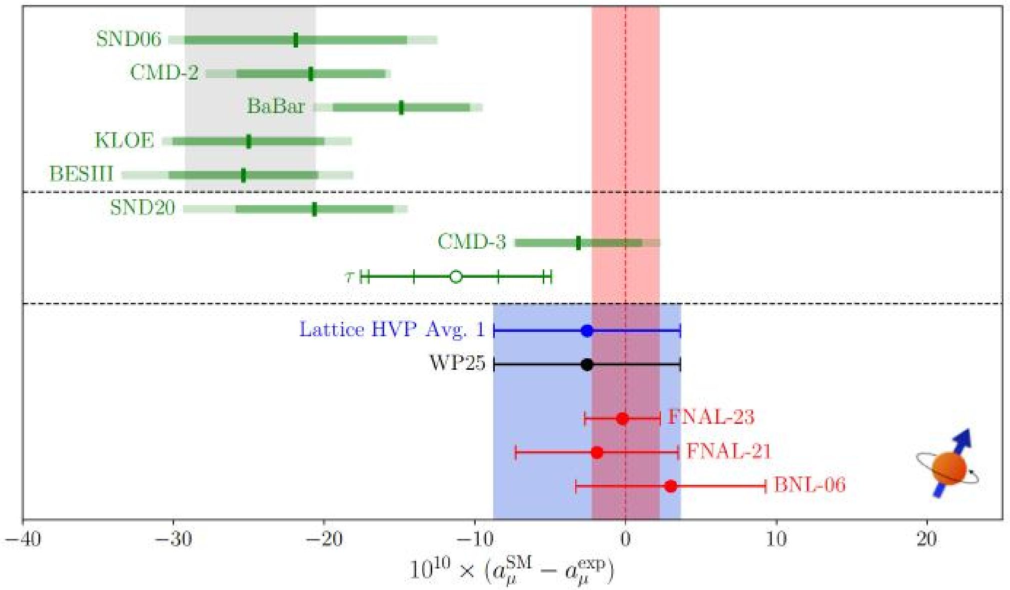
Outline

- Motivation
- Data set and MC sample
- $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$
  - Event selection
  - Branching fraction measurement
- $\tau^+ \to K^+\pi^0\overline{\nu}_\tau$
  - Event selection
  - Branching fraction measurement
- Summary

Motivation

- The anomalous magnetic moment of the muon $a_\mu = \frac{g_\mu - 2}{2}$ measured by different methods shows significant discrepancies.
- Currently, there remains a considerable difference regarding whether a_μ is consistent with the predictions of the Standard Model.



- The difference between the experimental and theoretical values of a_μ, obtained from the cross-section measurement of $e^+e^- \to \pi^+\pi^-$ and the mass spectrum of $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$,is very large (e τ puzzle).
- Study of $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ helps to provide experimental inputs required for the theoretical calculation of a_μ.

Motivation

PDG(2024): from independent measurements

$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9984 \pm 0.0007$

$\Longleftrightarrow$ 2.3 σ

Through CKM unitarity:

$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$

- $|V_{ud}|$:Most precise.
- $|V_{us}|$:The results for kaon and tau show a 2.2 σ deviation.
- $|V_{ub}|$:Small ($|V_{ub}|^2 \cong 1.7 \times 10^{-5}$) .

Kaon:2.3 σ tension from unitarity

$|V_{us}|$=0.22431 ± 0.00085

Tau:3.7 σ tension from unitarity

$|V_{us}|$== 0.2207 ± 0.0014

- The τ lepton decays to hadronic final states occur via W - exchange, and the decay rates to final states containing a strange quark suppressed by the factor $(|V_{us}|/|V_{ud}|)^2$.
- $|V_{us}|$ can be determined from the inclusive sum of the branching fractions of $\tau^+ \to K^+\pi^0\overline{\nu}_\tau$.

Data set and MC sample

Data: $\sqrt{s}$= 3.773 GeV 11088.8 pb^{-1}

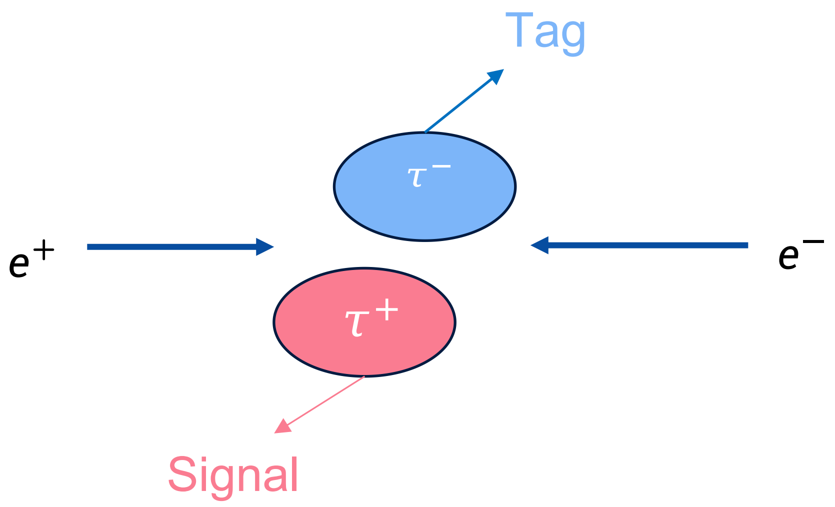
- Software environment : Boss 7.1.2
- Inclusive MC: Round 03&04&16 (10× data size)
- ditau Inclusive MC (3 × data size) is generated by Generator model: KKMC/tauola.

Data: $\sqrt{s}$= 4.270 GeV 531.1 pb^{-1}

- Software environment : Boss 7.0.3
- Inclusive MC: hadrons(5× data size) , ditau(13 × data size) , dimu(1× data size) , digamma(1× data size) , Bhabha(0.1× data size).

Directory	Process
D0D0[1]	$e^+e^- \to \psi(3770) \to D^0\bar{D}^0$
D+D-[2]	$e^+e^- \to \psi(3770) \to D^+D^-$
ditau[2]	$e^+e^- \to \tau^+\tau^-$
nonDD[2]	$e^+e^- \to \psi(3770) \to \text{non}-D\bar{D}$
qq[2]	$e^+e^- \to q\bar{q}$
RR2S[2]	$e^+e^- \to \gamma_{\rm ISR}\psi(2S)$
RR1S[2]	$e^+e^- \to \gamma_{\rm ISR}J/\psi$
Bhabha[3]	$e^+e^- \to e^+e^-$
digamma[3]	$e^+e^- \to \gamma\gamma$
dimu[3]	$e^+e^- \to \mu^+\mu^-$

Double tag method



$$B = \frac{N_{\text{sig}}}{2N_{\tau\tau}\varepsilon B(\tau^- \to e^-\nu_\tau\bar{\nu}_e)B(\pi^0 \to \gamma\gamma)}$$

N_{sig}: Signal yields

ε : $\tau^- \to e^-\nu_\tau\bar{\nu}_e$ and $\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$ / $\tau^+ \to K^+\pi^0\bar{\nu}_\tau$ efficiency

Tag: $\tau^- \to e^-\nu_\tau\bar{\nu}_e$

Signal:
1. $\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$, $\pi^0 \to \gamma\gamma$
2. $\tau^+ \to K^+\pi^0\bar{\nu}_\tau$, $\pi^0 \to \gamma\gamma$

$$\tau^+ \rightarrow \pi^+\pi^0\overline{\nu}_\tau$$

Event selection

- **Charge tracks**

V_{xy}<1cm, $|V_z|$ <10cm

cosθ<0.93;

- **π^0 Reconstruction**

$0.05 \le M_{\gamma\gamma} \le 0.20\text{GeV}/c^2$

χ^2<200(1-c kinematic)

- **Photon selection**

E_γ> 0.025 GeV for $|cos\theta|$ <0.8

E_γ> 0.050 GeV for $0.86 < |cos\theta| < 0.92$

$0 \le \text{TDC} \le 14(\times 50\text{ns})$

$N_\gamma \ge 2$

- **PID requirement**

Using PID system: ParticalPID(use dE/dx,TofCorr)

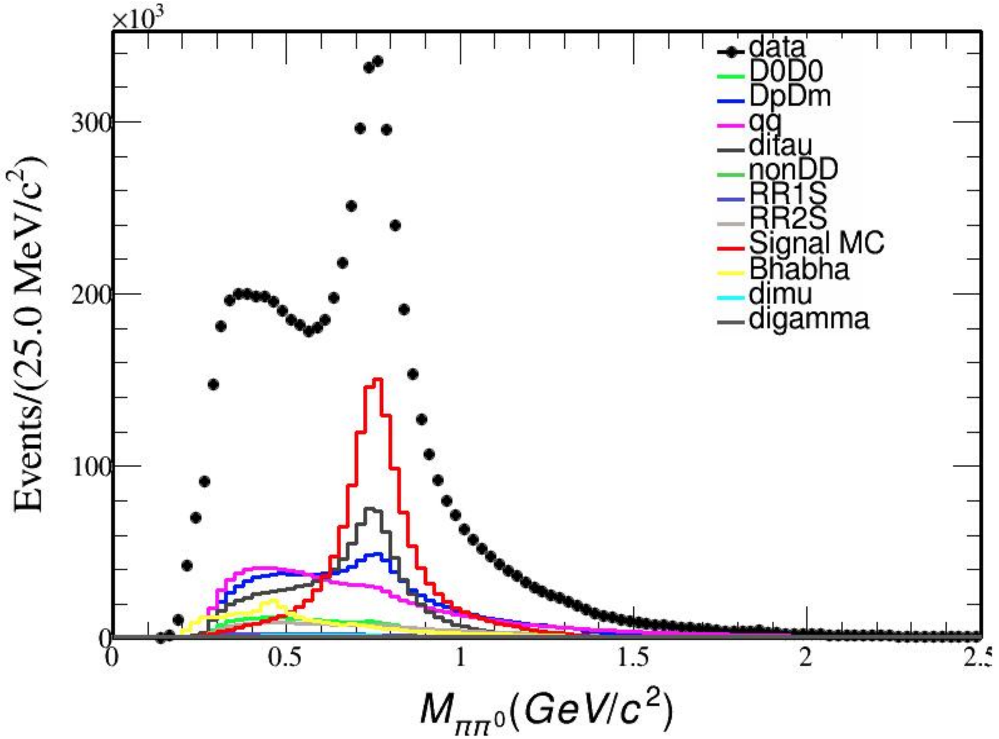
e :$Prob_e > Prob_\pi; Prob_e > Prob_K$

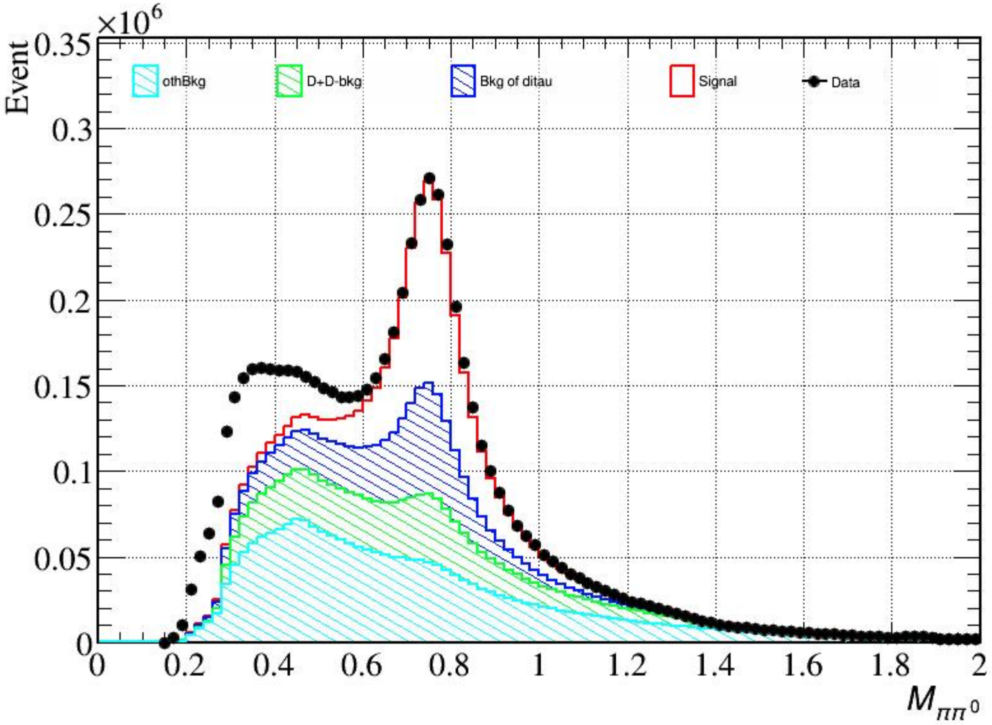
π :$Prob_\pi > Prob_e; Prob_\pi > Prob_K$

$N_\pi = 1$, $N_e = 1$

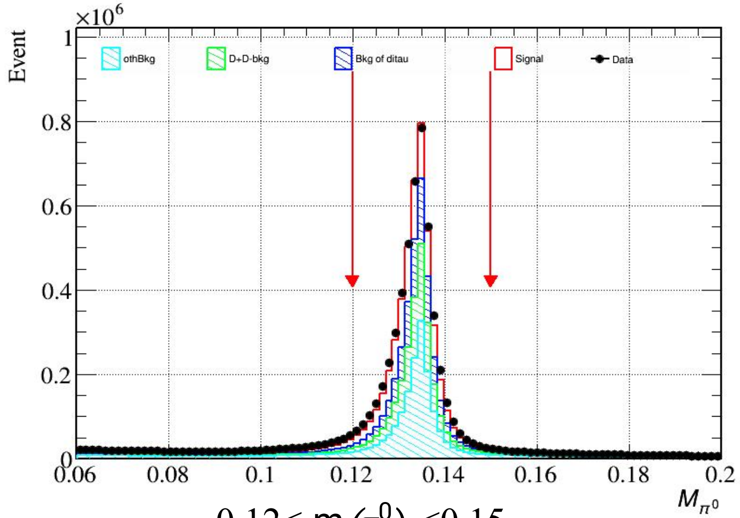
Signal selection criteria

$\mathrm{m}(\pi^+\pi^0)$ is used to identify semileptonic decay, combined tag and signal selection

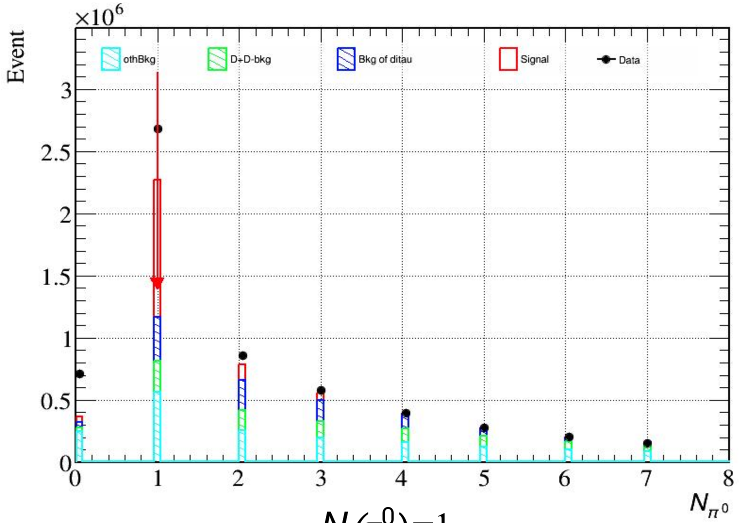




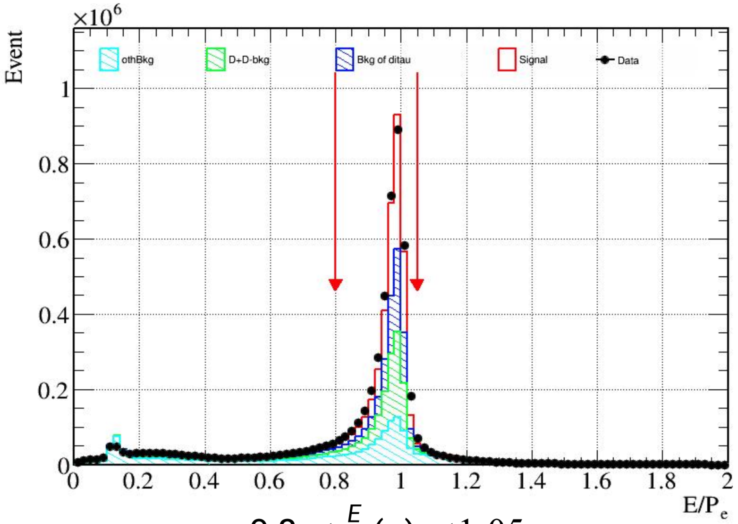
$\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ Event selection $\sqrt{s} =$ 3.773 GeV



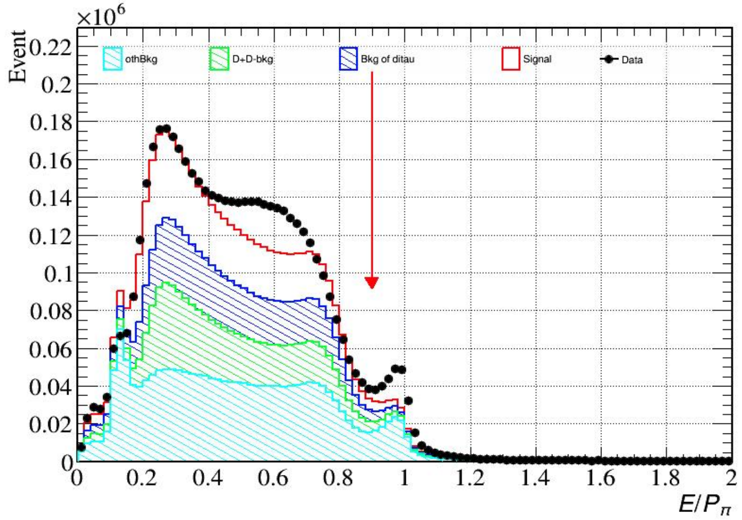
0.12< m(π^0) <0.15



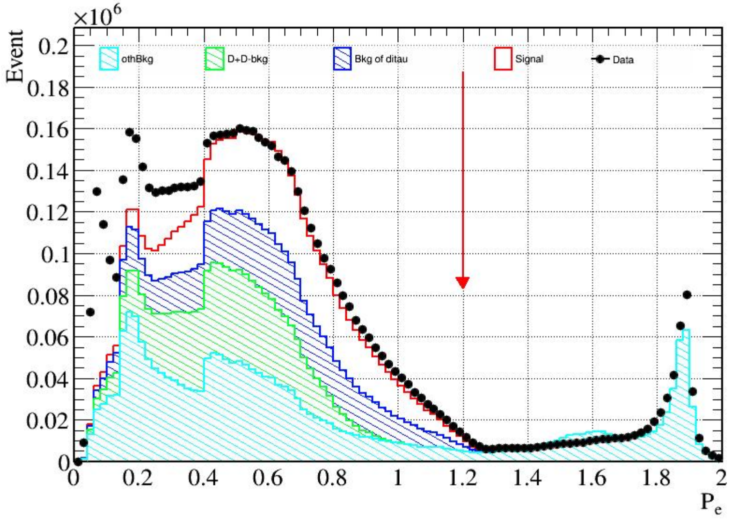
$N(\pi^0)$=1



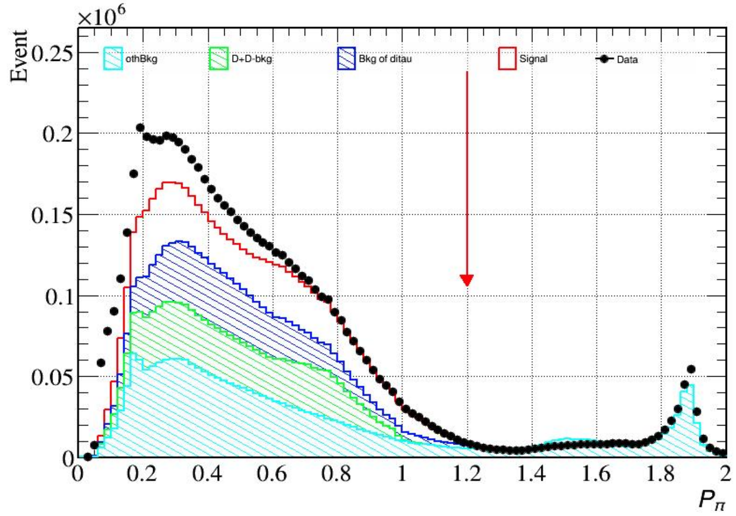
$0.8 < \frac{E}{P}(e) < 1.05$



$\frac{E}{P}(\pi) < 0.9$



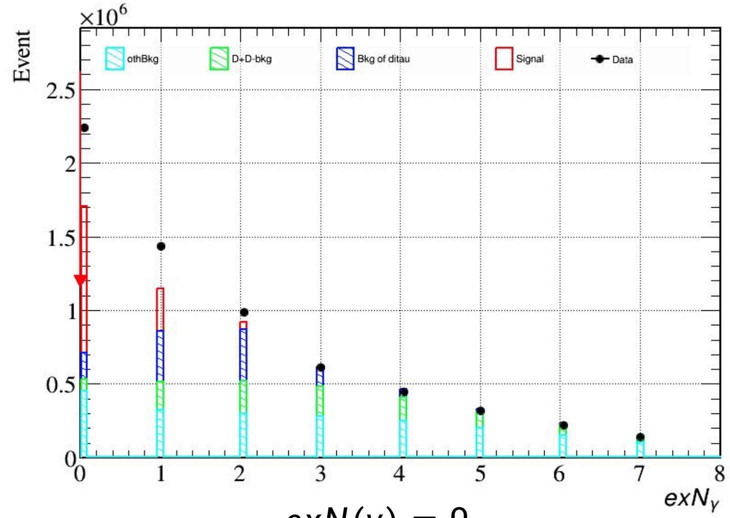
$P_e < 1.2$



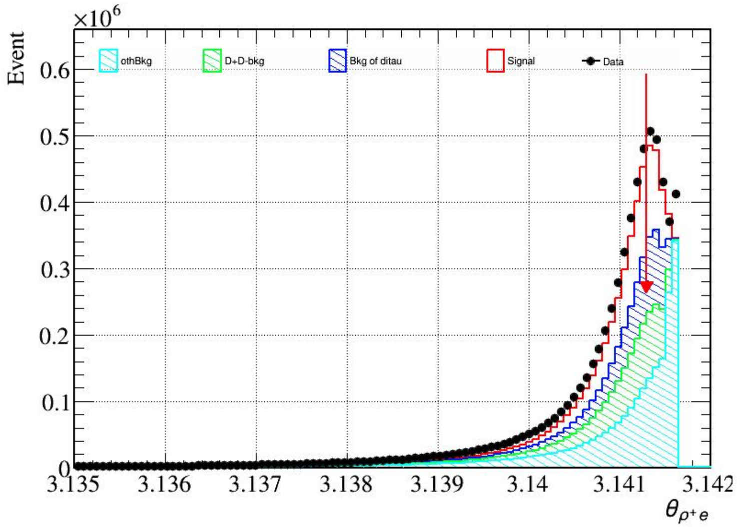
$P_\pi < 1.2$

Event selection

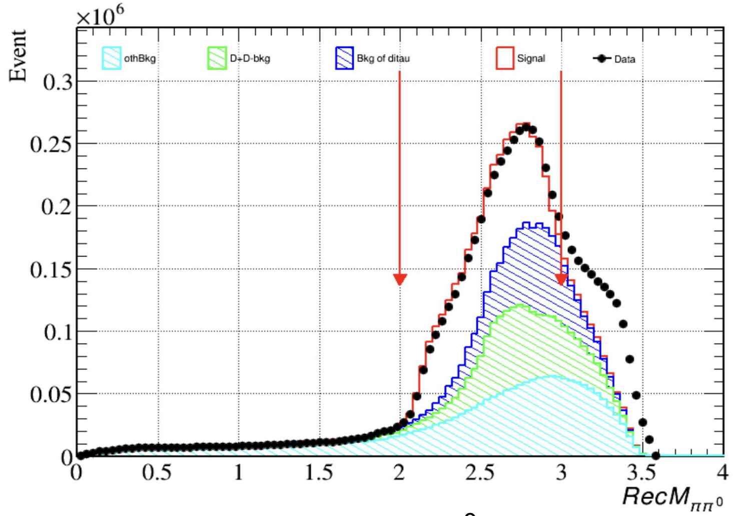
$\sqrt{s} =$ 3.773 GeV



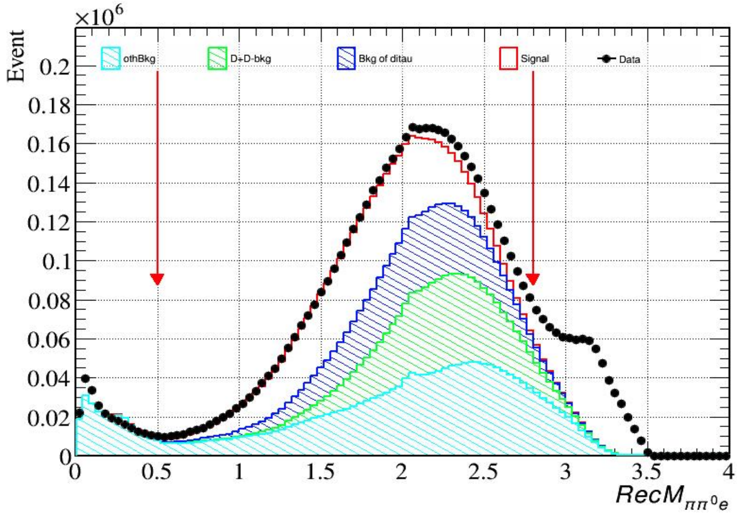
$exN(\gamma) = 0$



$\theta(\rho e)$<3.1413



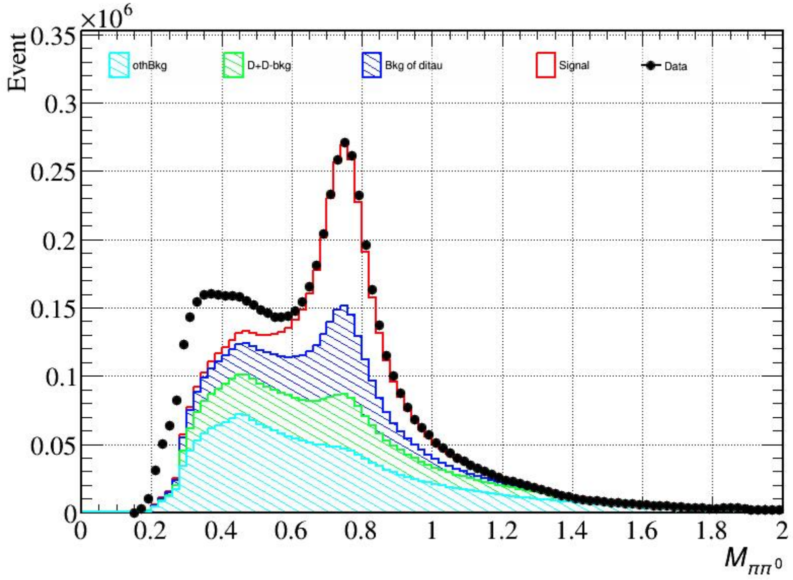
2< mrec$(\pi\pi^0)$ <3



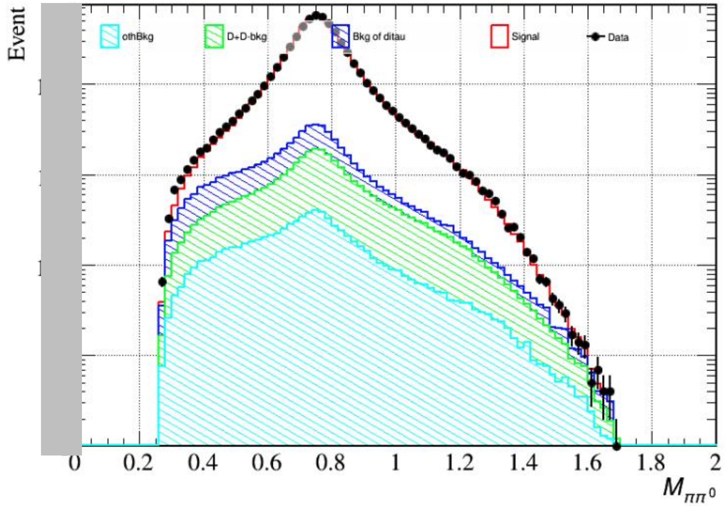
0.5< mrec$(\pi\pi^0 e)$ <2.8

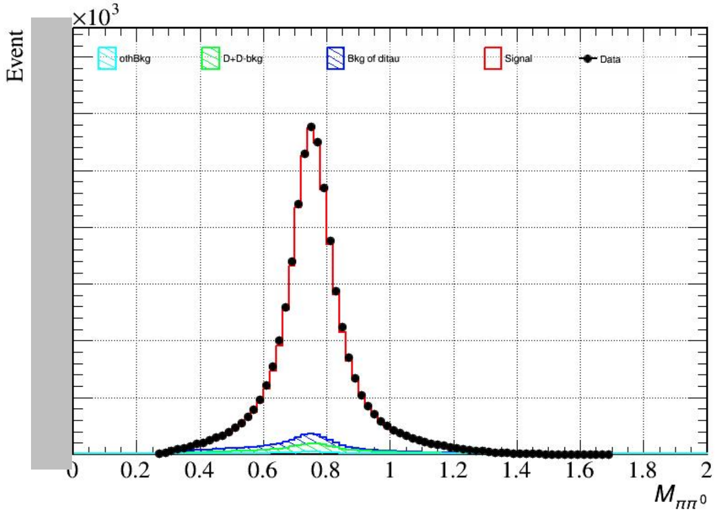
Signal selection criteria

- The proportion of background：8.49%
- The efficiency:20.1%



$0.12< m(\pi^0) <0.15$, $\frac{E}{P}(\pi) <0.9$,
$0.8 < \frac{E}{P}(e) <1.05$, $P_e < 1.2$,
$P_\pi < 1.2$, $N(\pi^0)=1$,
$\theta(\rho e)<3.1413$, $e x N(\gamma) = 0$
$2< mrec(\pi\pi^0) <3$,
$0.5< mrec(\pi\pi^0 e) <2.8$

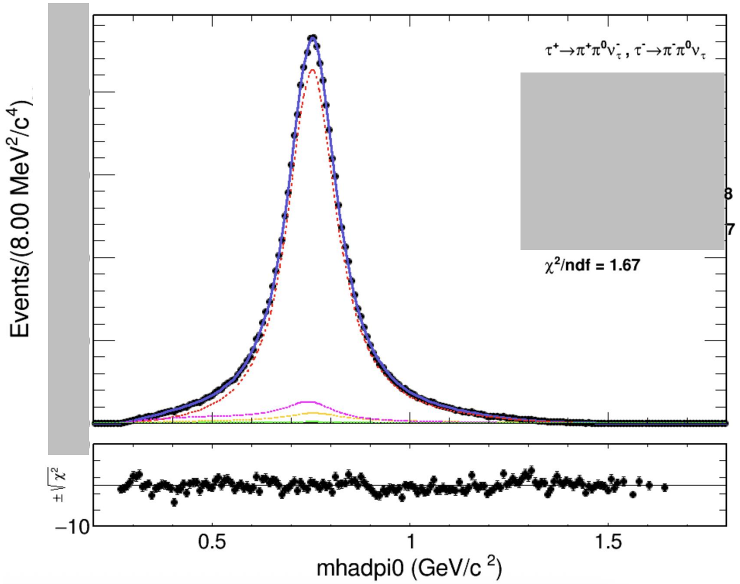


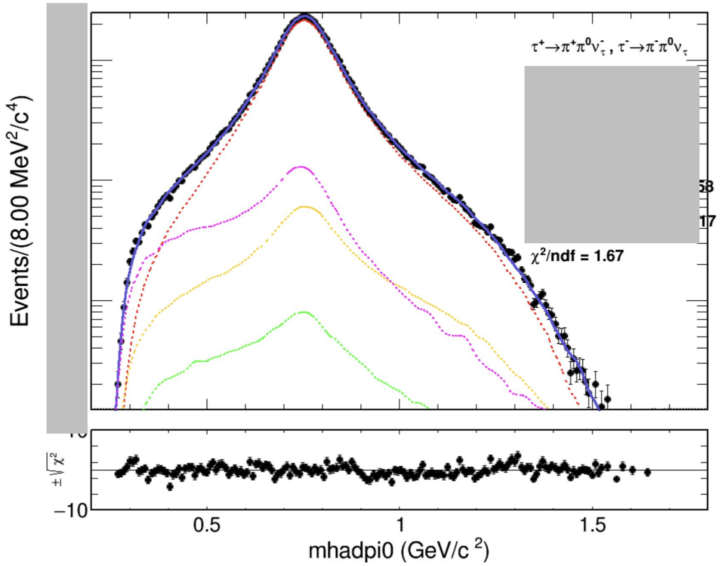


Signal Fit

$\sqrt{s}$= 3.773 GeV

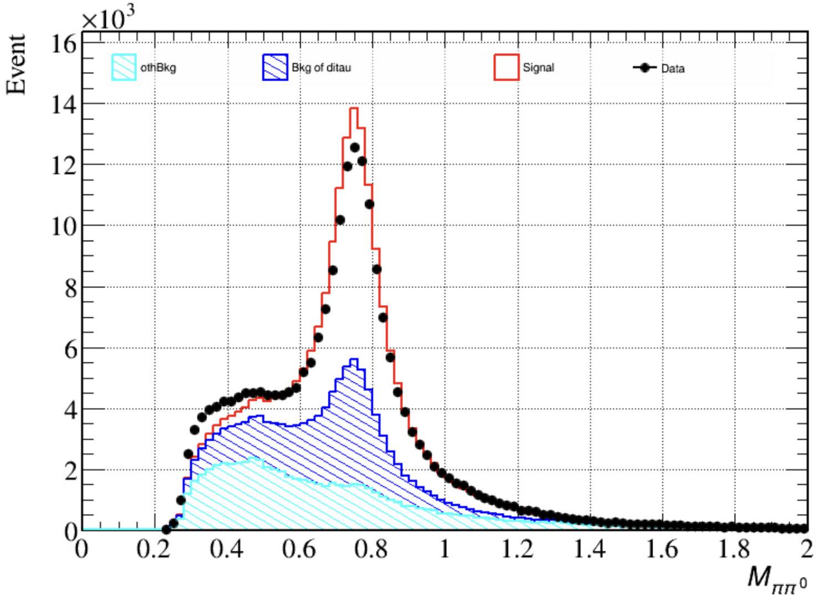
- Signal shape: signal MC (Based on inclusive MC) simulation⊗ Gaussian function;
- Background shape: From inclusive MC⊗ Gaussian function.





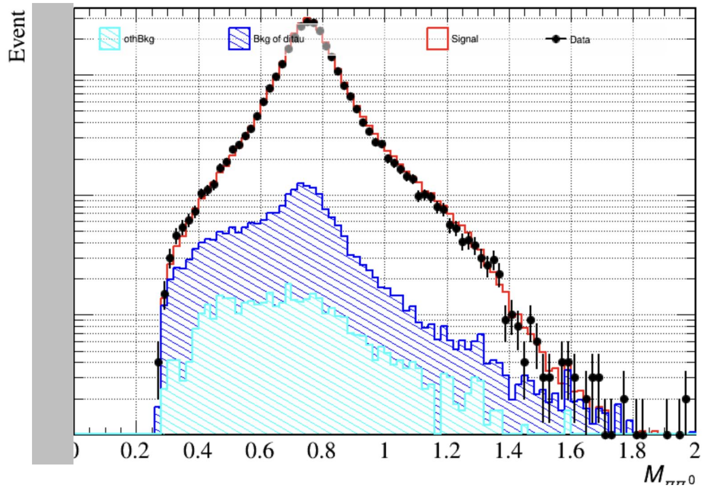
Signal selection criteria

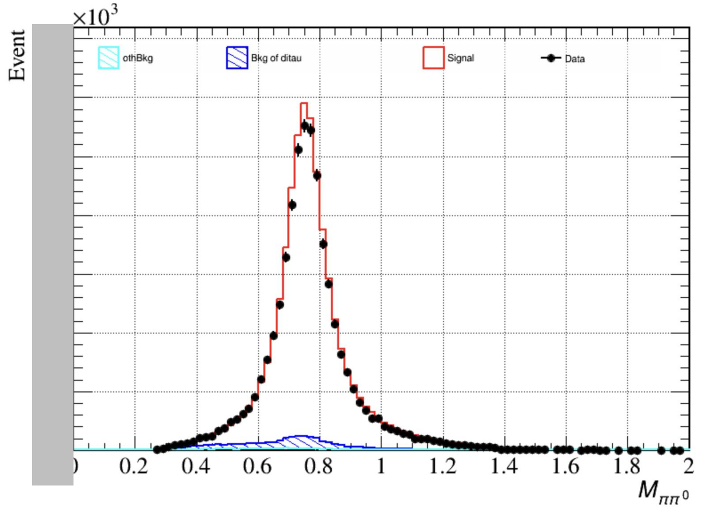
At $\sqrt{s}$ = 4.270 GeV, the cut conditions are only slightly modified.



$0.12 < m(\pi^0) < 0.15$, $\frac{E}{P}(\pi) < 1.11$,
$0.8 < \frac{E}{P}(e) < 1.05$, $P_e < 1.6$,
$P_\pi < 1.59$, $N(\pi^0) = 1$,
$\theta(\rho e) < 3.1413$, $exN(\gamma) = 0$,
$1.22 < mrec(\pi\pi^0) < 3$,
$mrec(\pi\pi^0 e) < 2.8$

- The proportion of background： 7.12%
- The efficiency:15.85%

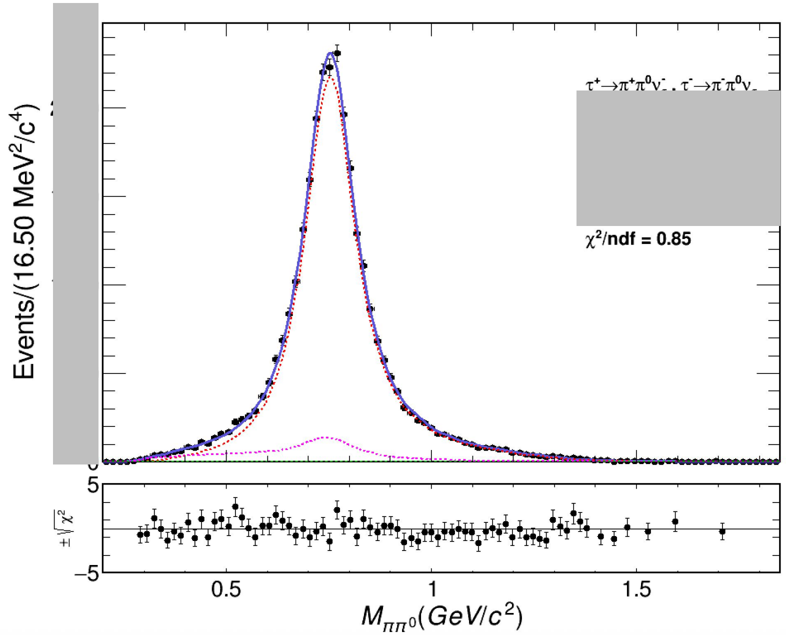


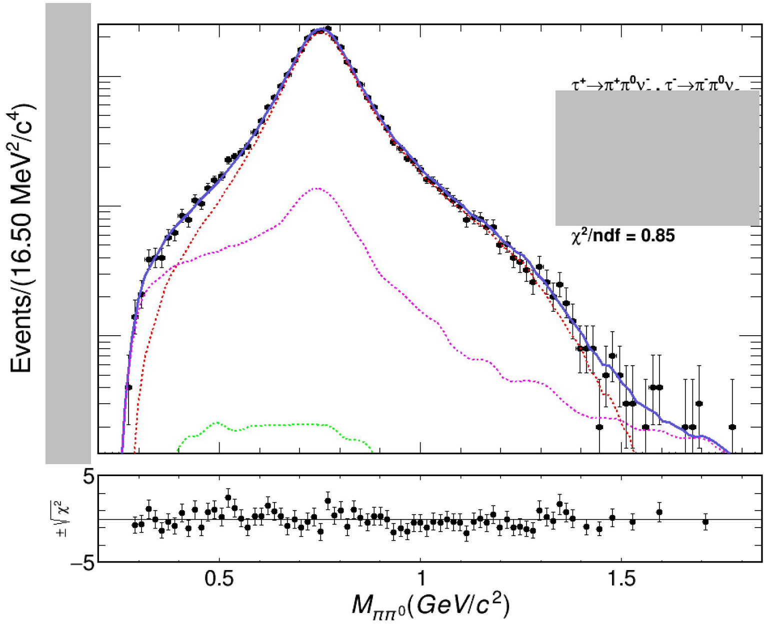


Signal Fit

$\sqrt{s}$= 4.270 GeV

- Signal shape: signal MC (Based on inclusive MC) simulation⊗ Gaussian function;
- Background shape: From inclusive MC⊗ Gaussian function.





Calculation details

- $B(\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau) = \frac{N_{sig}}{2N_{\tau\tau}\varepsilon B(\tau^-\to e^-\nu_\tau\overline{\nu}_e)B(\pi^0\to\gamma\gamma)}$

  where $\varepsilon \pm \varepsilon_{err} = \varepsilon \pm \frac{\sqrt{N_{sel}}}{N_{gen}}$, $N_{\tau\tau} = L \times \sigma$, $N_{\tau\tau err} = N_{\tau\tau} \times \frac{L_{err}}{L}$

- $input = B(\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau) \times \sqrt{(\frac{B_{(\tau^-\to e^-\nu_\tau\overline{\nu}_e)err}}{B_{(\tau^-\to e^-\nu_\tau\overline{\nu}_e)}})^2 + (\frac{N_{\tau\tau err}}{N_{\tau\tau}})^2 + (\frac{B_{(\pi^0\to\gamma\gamma)err}}{B_{(\pi^0\to\gamma\gamma)}})^2}$

  $stat. = B(\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau) \times \sqrt{(\frac{N_{sigerr}}{N_{sig}})^2 + (\frac{\varepsilon_{err}}{\varepsilon})^2}$

Parameter	value		from
	$\sqrt{s}$= 3.773 GeV	$\sqrt{s}$= 4.270 GeV	
$B_{(\tau^-\to e^-\nu_\tau\overline{\nu}_e)}$	0.1782±0.0004	same	PDG
$B_{(\pi^0\to\gamma\gamma)}$	0.9880±0.00034	same	PDG
L	11088.8±0.2±13.8±31	531.1 ±0.1 ± 0.31	http://bes3.ihep.ac.cn
σ	2.652	3.479	MC simulation

Measurement result

	Our work(3.773 GeV)	Our work(4.270 GeV)	ALEP	Belle
Bf(%)			25.47	25.24
Statistic			0.097(0.38%)	0.01(0.04%)
input Systematic/sys.			0.085(0.33%)	0.39(1.55%)
N_{sigerr}			——	——
ε_{err}			——	——
$B(\tau^- \to e^-\nu_\tau\overline{\nu}_e)err$			——	——
$N_{\tau\tau err}$			——	——
$B(\pi^0 \to \gamma\gamma)err$			——	——
Total uncertainty			0.129(0.51%)	0.39(1.5%)

$$\tau^+ \to K^+\pi^0\overline{\nu}_\tau$$

Event selection

- The Event selection for charge tracks , π^0reconstruction and photon selection in process of $\tau^+ \to K^+\pi^0\overline{\nu}_\tau$ are the same as for the previous channel.
- PID requirement:

  Using PID system: ParticalPID(use dE/dx,TofCorr)

  e :$Prob_e$>$Prob_\pi$;$Prob_e > Prob_K$;$Prob_e$ >0.001;

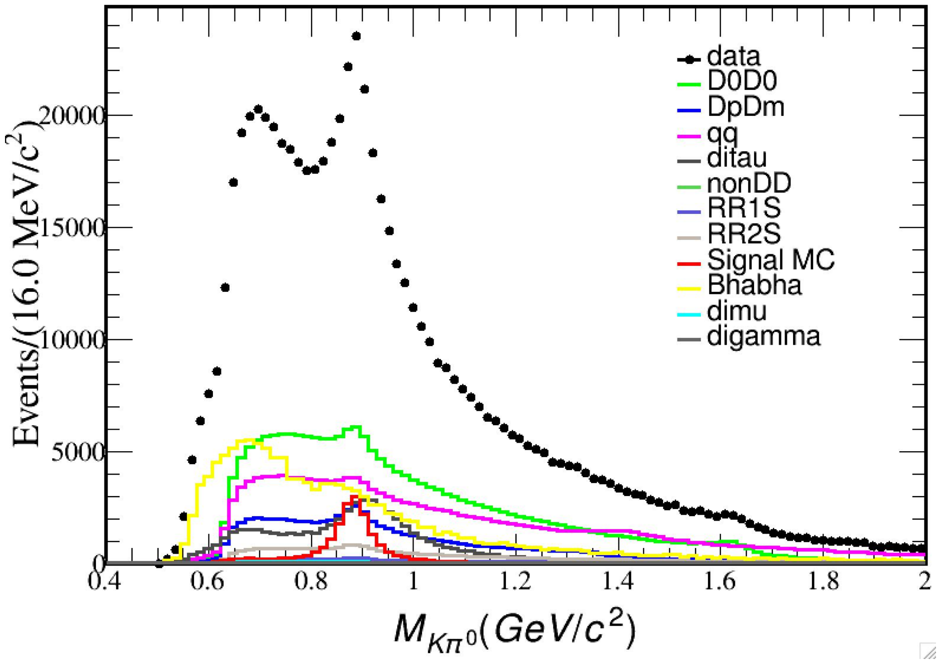
  K :$Prob_K$>$Prob_e$;$Prob_K > Prob_\pi$;$Prob_K$ >0.001;

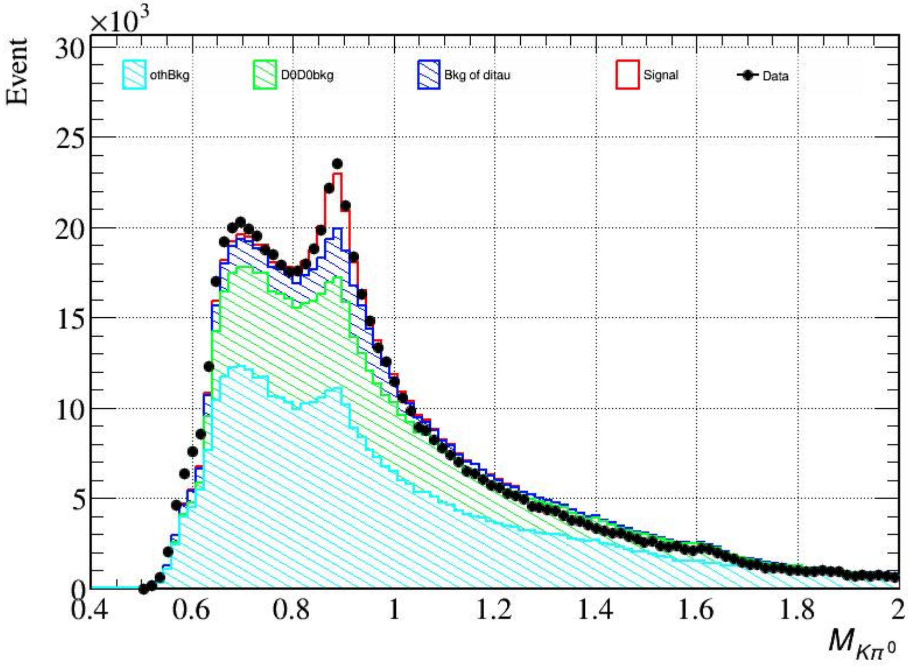
  N_K =1, $N_e = 1$

Event selection

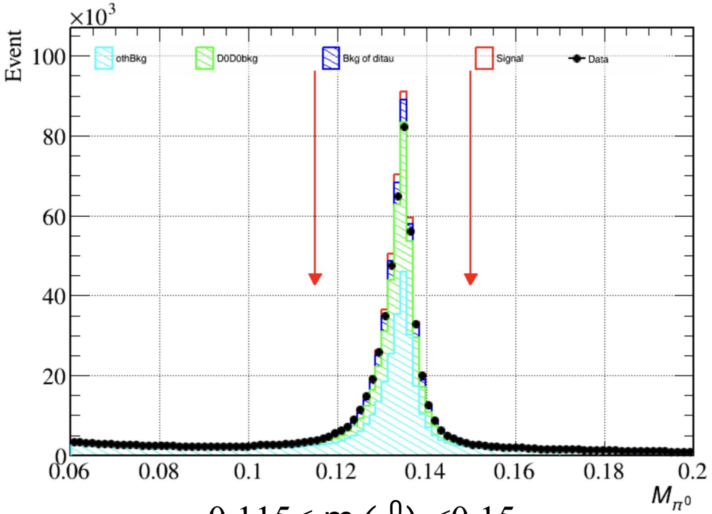
Signal selection criteria

$m(K^+\pi^0)$ is used to identify semileptonic decay, combined tag and signal selection

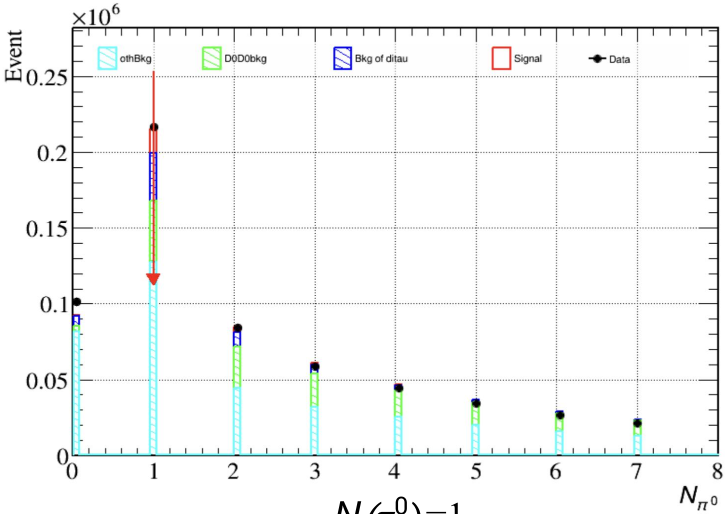




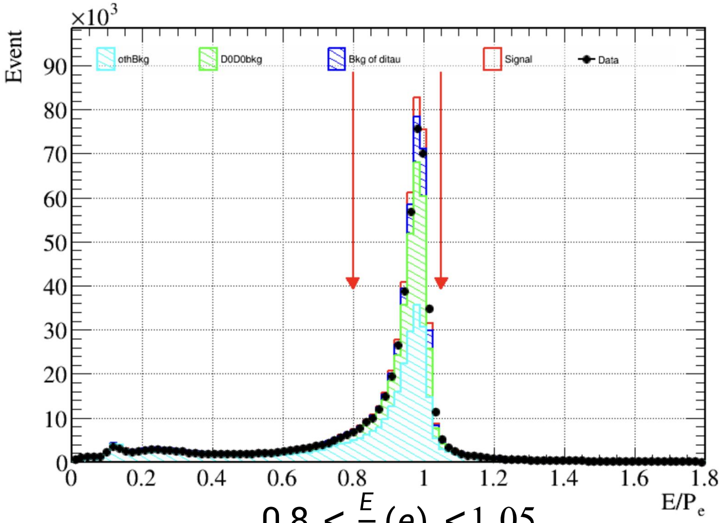
Event selection



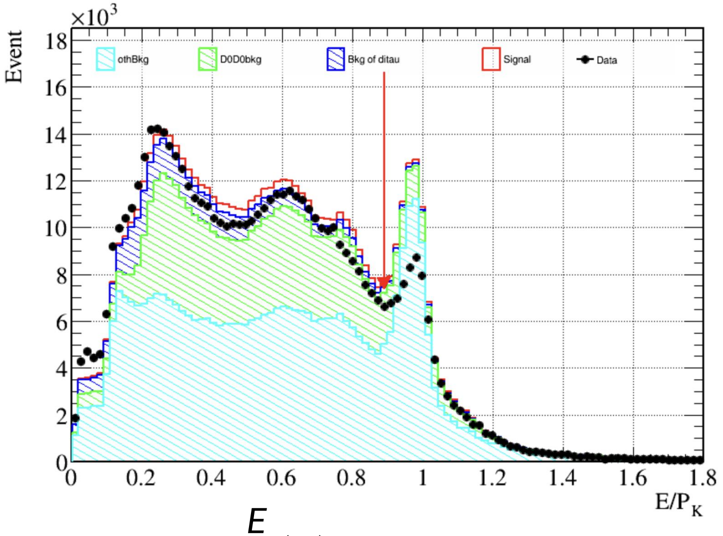
0.115< m (π^0) <0.15



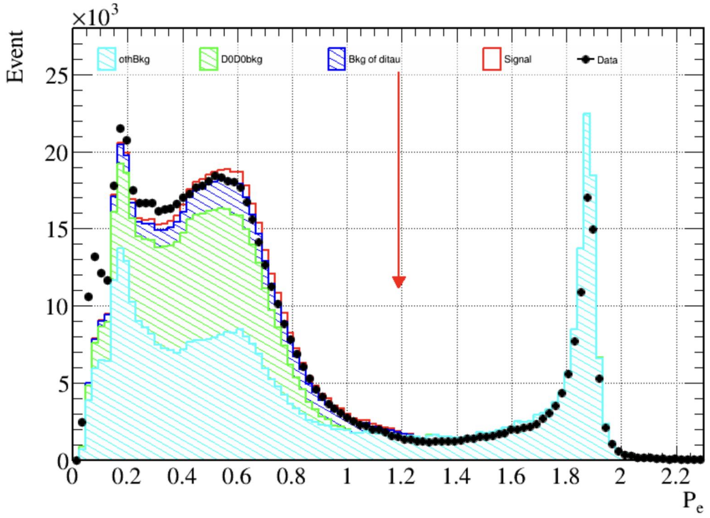
$N(\pi^0)$=1



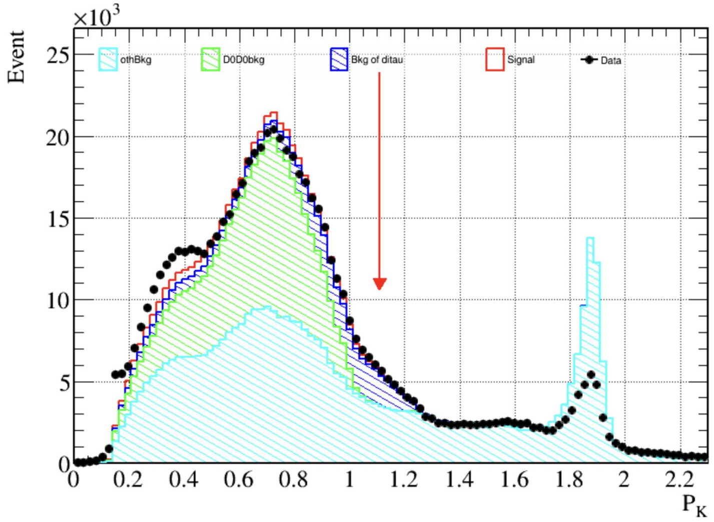
$0.8 < \frac{E}{P}(e) < 1.05$



$\frac{E}{P}(K) < 1.3$

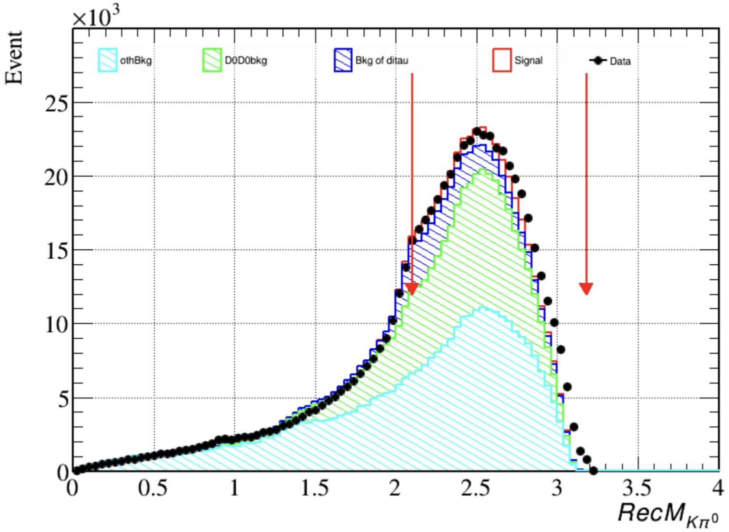


$P_e < 1.2$

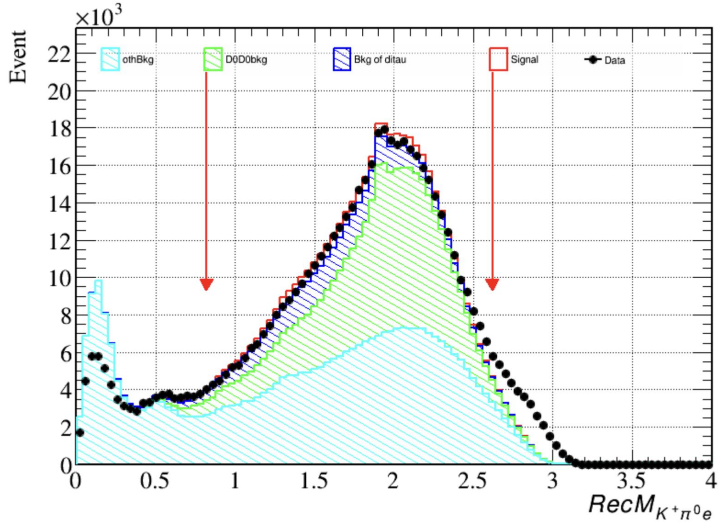


$P_K < 1.2$

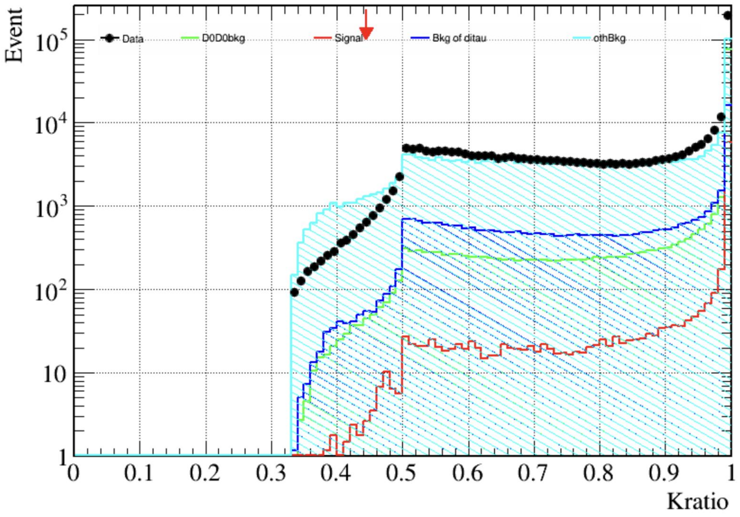
Event selection



2< mrec $(K\pi^0)$ <3



0.5< mrec $(K\pi^0 e)$ <2.5

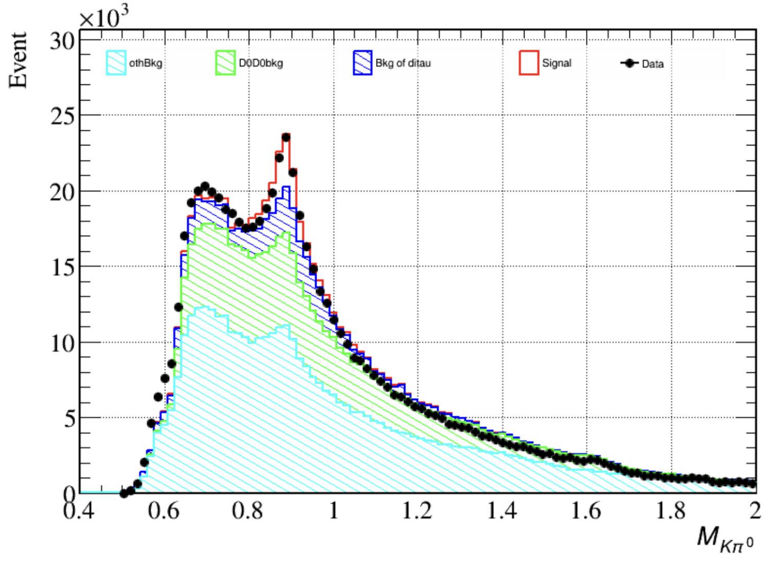


Kratio>0.445

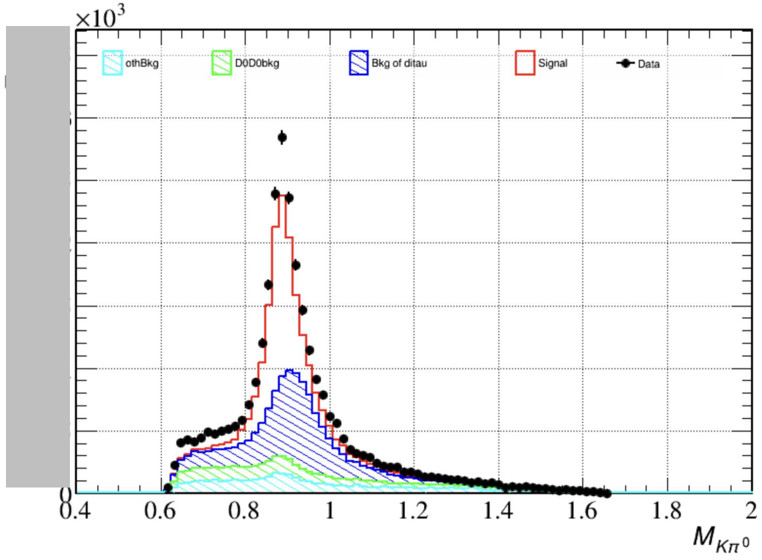
$$Kratio = \frac{Prob_k}{Prob_k + Prob_\pi + Prob_e}$$

Signal selection criteria

- The proportion of background：62.02%
- The efficiency:16.67%



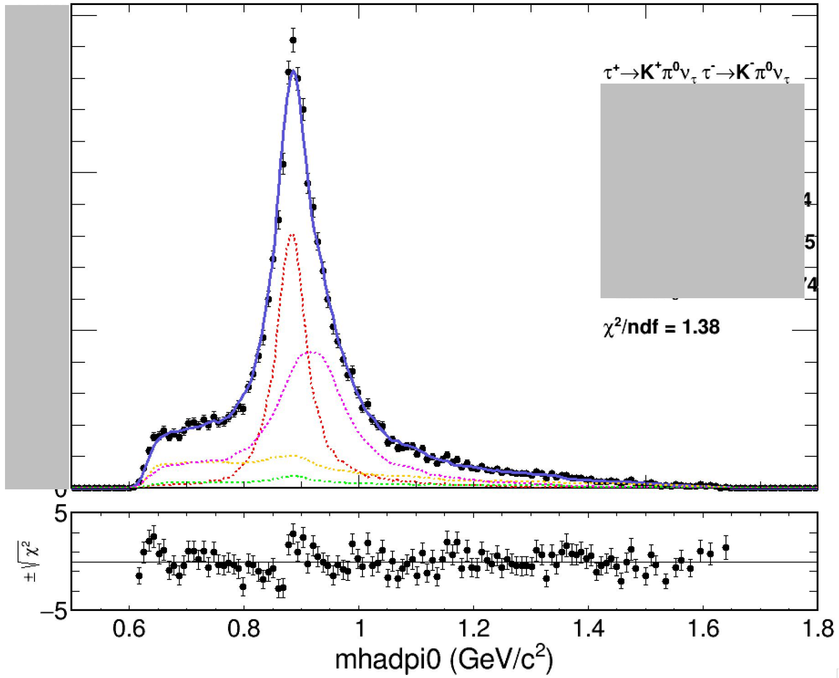
$0.115 < m(\pi^0) < 0.15$, $\frac{E}{P}(K) < 0.89$,
$0.8 < \frac{E}{P}(e) < 1.05$,
$0.23 < P_e < 1.19$, $P_K < 1.11$,
$N(\pi^0)=1$, $2.1 < mrec(K\pi^0) < 3.18$,
$0.82 < mrec(K\pi^0 e) < 2.62$,
Kratio>0.445



Signal Fit

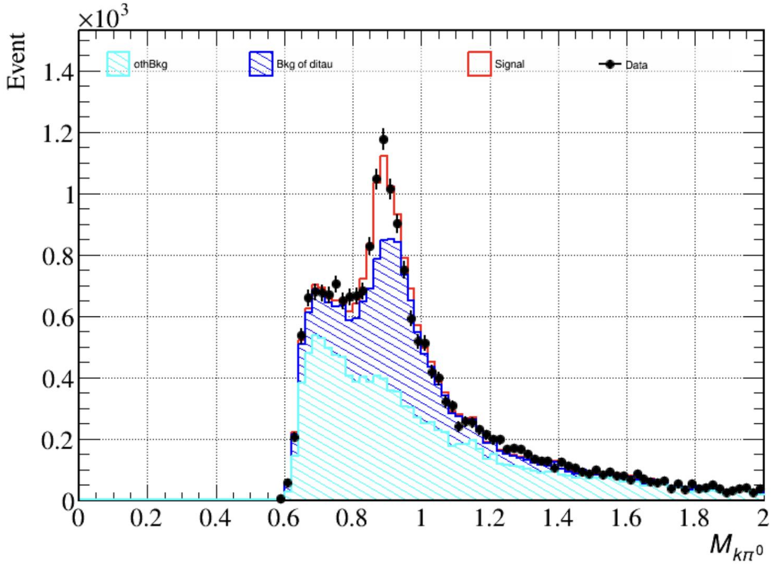
$\sqrt{s}$= 3.773 GeV

- Signal shape: signal MC (Based on inclusive MC) simulation⊗ Gaussian function;
- Background shape: From inclusive MC⊗ Gaussian function.



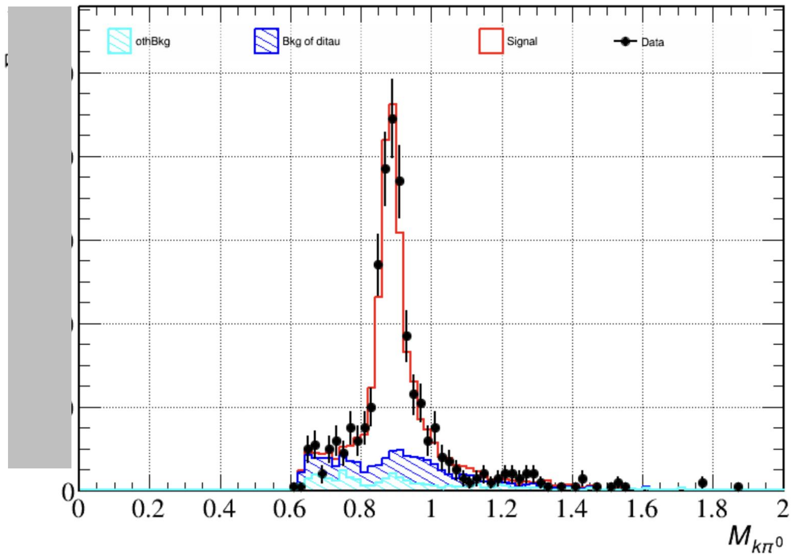
Signal selection criteria

At $\sqrt{s} = 4.270$ GeV, the cut conditions are only slightly modified.



$0.115 < m(\pi^0) < 0.15$,
$\frac{E}{P}(K) < 0.9$, $0.8 < \frac{E}{P}(e) < 1.05$,
$P_e < 1.63$, $P_K < 0.77$,
$N(\pi^0) = 1$, $1.34 < mrec(K\pi^0) < 3.1$,
$mrec(K\pi^0 e) < 2.5$,
Kratio>0.515

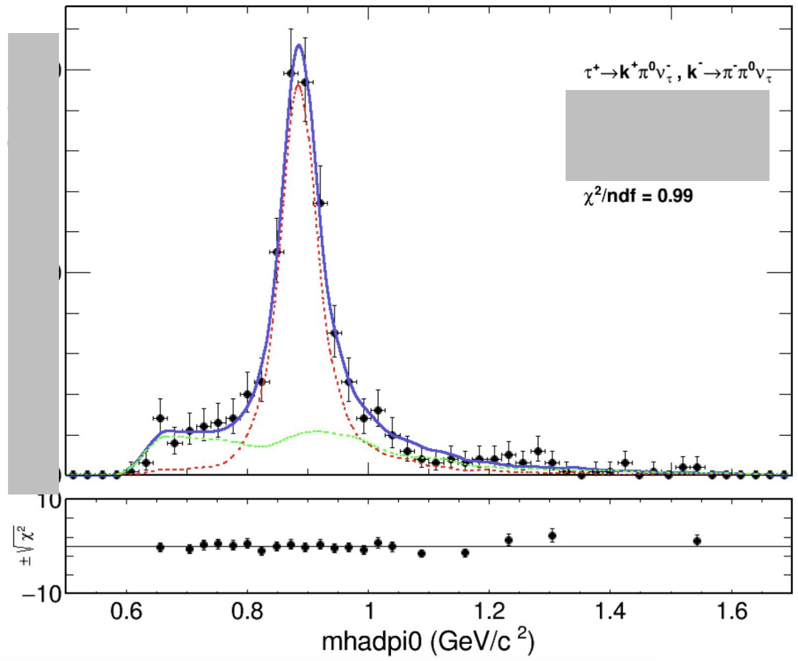
- The proportion of background：33.57%
- The efficiency:11.61%



Signal Fit

$\sqrt{s}$= 4.270 GeV

- Signal shape: signal MC (Based on inclusive MC) simulation⊗ Gaussian function;
- Background shape: From inclusive MC⊗ Gaussian function.



Measurement result

	Our work(3.773 GeV)	Our work(4.270 GeV)	BABR	ALEP	CLEO
Bf(10^{-3})			4.16	4.71	4.44
Statistic			0.03(0.72%)	0.59(12.53%)	0.26(5.86%)
input Systematic/sys.			0.18(4.33%)	0.23(4.88%)	0.24(5.41%)
N_{sigerr}			——	——	——
ε_{err}			——	——	——
$B(\tau^- \to e^-\nu_\tau\overline{\nu}_e)err$			——	——	——
$N_{\tau\tau err}$			——	——	——
$B(\pi^0 \to \gamma\gamma)err$			——	——	——
Total uncertainty			0.182(4.3%)	0.633(13.4%)	0.354(7.96%)

Summary

➢ We have measured the branching fraction of the decay $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ and $\tau^+ \to K^+\pi^0\overline{\nu}_\tau$ with data samples at 3.773 GeV, using a luminosity of 11088.8 pb⁻¹, and at 4.270 GeV, using a luminosity of 531.1 pb⁻¹.

$\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$	branching fraction(%)
Our work(3.773 GeV)	
Our work(4.270 GeV)	
PDG	25.49 ± 0.09
$\tau^+ \to K^+\pi^0\bar{\nu}_\tau$	branching fraction(10^{-3})
Our work(3.773 GeV)	
Our work(4.270GeV)	
PDG	4.33 ± 0.15

Summary

Next to do

- To improve fitting and fit with physical formulas.
- To consider systematic uncertainties, etc.