Study of τ decays at STCF

Shanshan Li[1], Shulei Zhang[1], Xiaolin Kang[2], Huijing Li[3], Xiaorong Zhou[4]

[1]Hunan University

[2]China University of Geosciences

[3]Henan Normal University

[4]University of Science and Technology of China

STCF物理模拟和探测器联合讨论会•合肥

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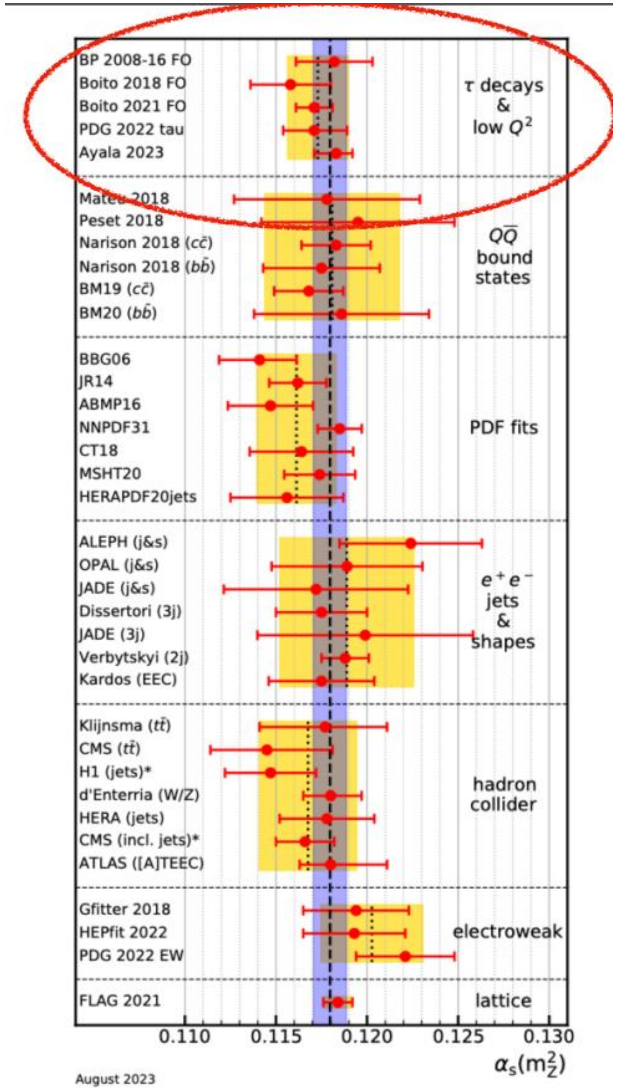
  - Event selection
  - Branching fraction measurement
- $\tau^+ \to K_S^0\pi^+\overline{\nu}_\tau$
  - Event selection
  - Branching fraction measurement
- Summary

Motivation

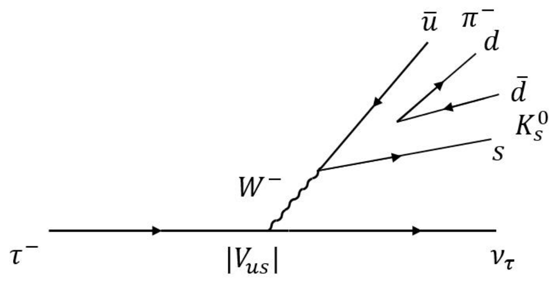
- The strong coupling constant α_s is a fundamental parameter of the Standard Model (SM) of particle physics and Quantum Chromodynamics (QCD). Measuring the branching ratio of $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ the decay process provides significant experimental input for determining α_s .

- Meanwhile , Study of $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$ can help to understand e τ puzzle, namely 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.



Motivation

- The τ lepton is the sole lepton with a mass large enough to decay into hadrons. Its decays to hadronic final states occur via W - exchange, and the decay rates to final states containing a strange quarkare suppressed by the factor $(|V_{us}|/|V_{ud}|)^2$.
- Given a value of m_s ,$|V_{us}|$ can be determined with unprecedented precision from the inclusive sum of the branching fractions of τ decays to hadronic final states with net strangeness equal to unity .



- Since the origin of CP violation (CPV) remains an unsolved problem, indicating there may be non - SM CPV sources, exploring CPV in the tauon sector, such as in the decay $\tau^+ \to K_S^0\pi^+\overline{\nu}_\tau$, provides a different and complementary landscape to seek CPV beyond the Standard Model (SM).

MC sample

$\sqrt{s}$= 3.773 GeV

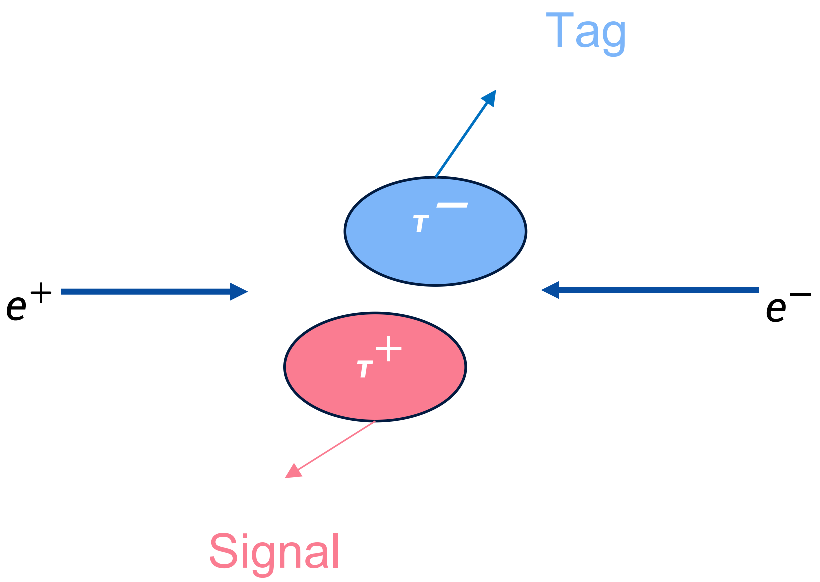
- 400,000 signal MC
- signal MC Generator model: tauhadnu.

$\sqrt{s}$= 4.260 GeV

- 3,000, 000 Inclusive ditau MC/11,000, 000 Inclusive ditau MC
- Inclusive ditau MC Generator model: madgraph5＋pythia8.
- signal MC : from ditau inclusive MC.

MC sample

Double tag method



$$B(\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau / \tau^+ \to K^+\pi^0\bar{\nu}_\tau)$$

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

N_{sig}: Signal yields

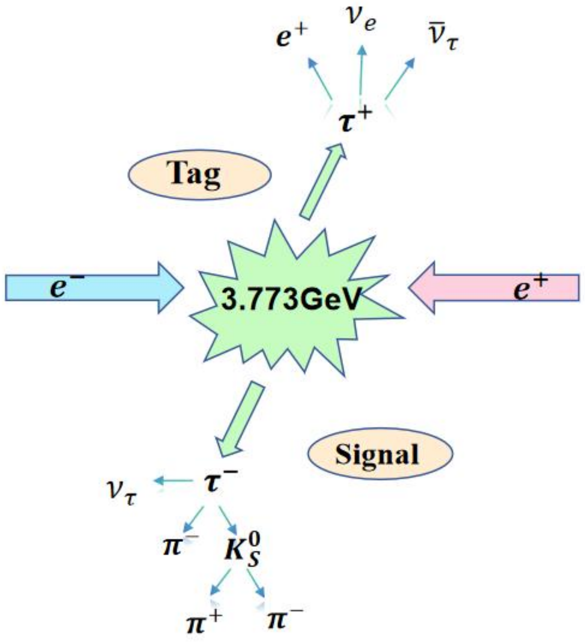
ε : $\tau^- \to e^-\nu_\tau\bar{\nu}_e$ and $\tau^+ \to \pi^+\pi^0\bar{\nu}_\tau$ / $\tau^+ \to K^+\pi^0\bar{\nu}_\tau$ efficiency

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

MC sample

Double tag method



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

N_{sig}: Signal yields

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

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

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

- **Charge tracks**

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

$\cos\theta$<0.93;

- **Photon selection**

E_γ> 0.025 GeV in the barrel section

E_γ> 0.050 GeV in the end cap

$0 \leq$ TDC $\leq$ 14(×50ns)

$N_\gamma \geq 2$

- **π^0 Reconstruction**

χ^2<200(1-c kinematic)

- **PID requirement**

Using PID system: Global PID

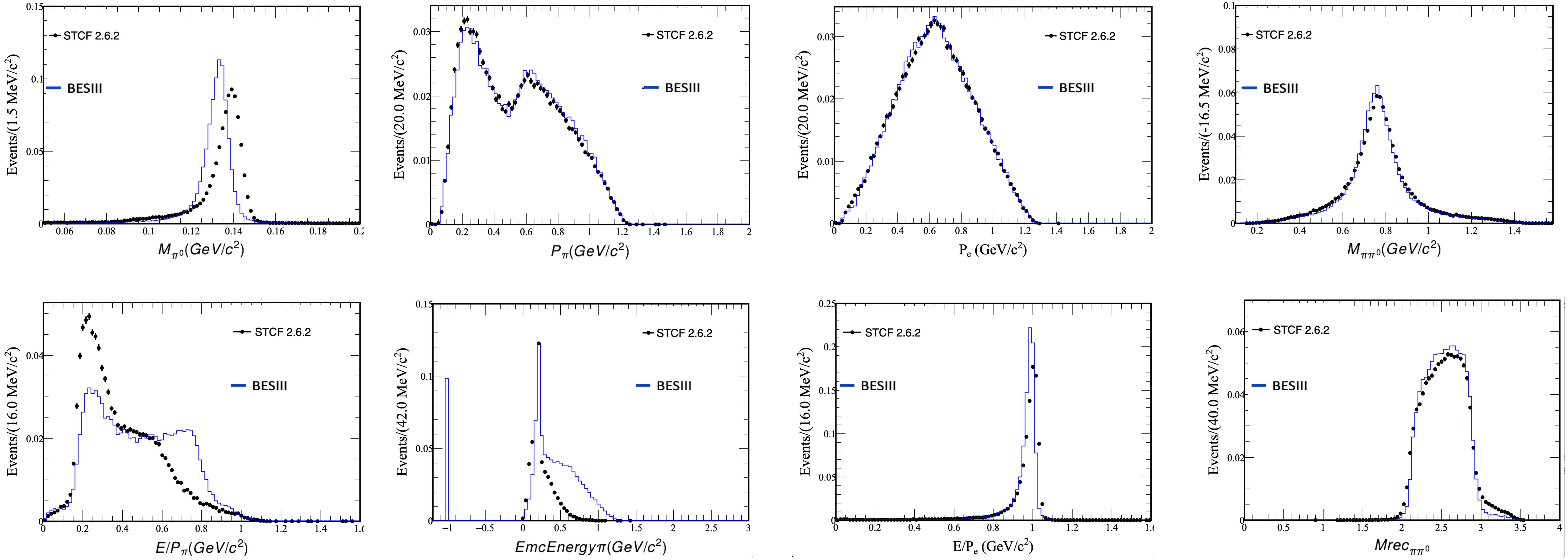
e :$Prob_e$>$Prob_\pi$;$Prob_e > Prob_K$

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

N_π =1, $N_e = 1$

Comparison chart

Compare with BESIII at $\sqrt{s}$ = 3.773 GeV



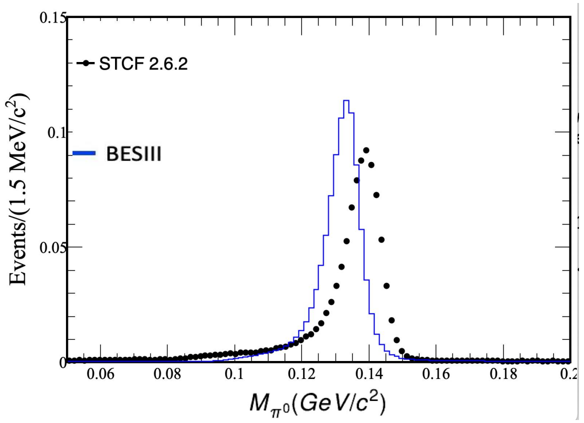
Comparison chart

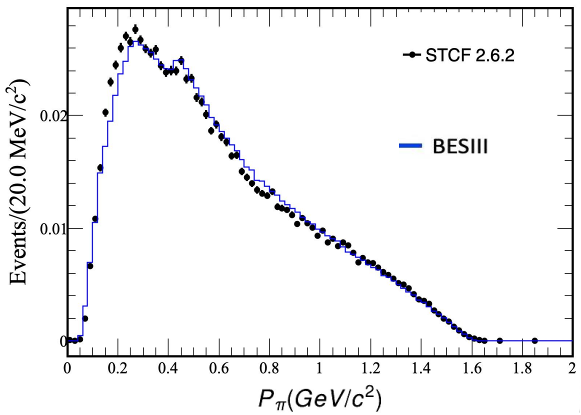
Compare with BESIII at $\sqrt{s}$ = 3.773 GeV

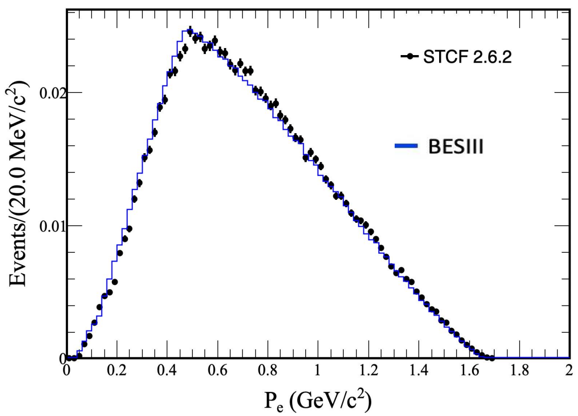
	SigMC num	Efficiency	BESIII efficiency
No cut	108515	55.08%	50.24%
0.12< $m(\pi^0)$ <0.15	82454	41.85%	43.94%
$\frac{E}{P}(\pi)$ <0.9, $0.8 < \frac{E}{P}(e)$ <1.05	70372	35.72%	39.18%
$P_e < 1.2$ $P_\pi < 1.2$	69968	35.52%	39.00%
$exN(\gamma)$ =1,$N(\pi^0)$ =1	65830	33.42%	30.36%
the(rhoe)<3.1413	43965	22.32%	20.63%
2< $mrec(\pi\pi^0)$ <3, 0.5< $mrec(\pi\pi^0 e)$ <2.8	43424	22.04%	20.47%

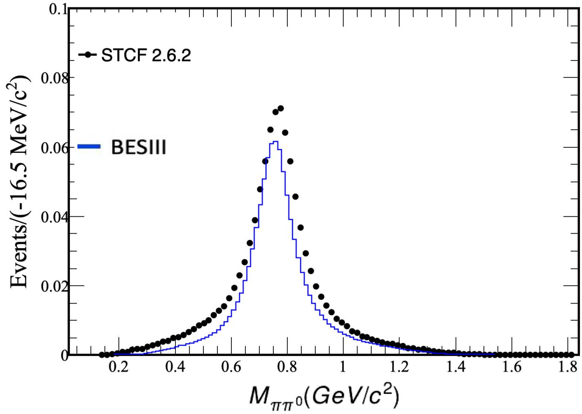
Comparison chart

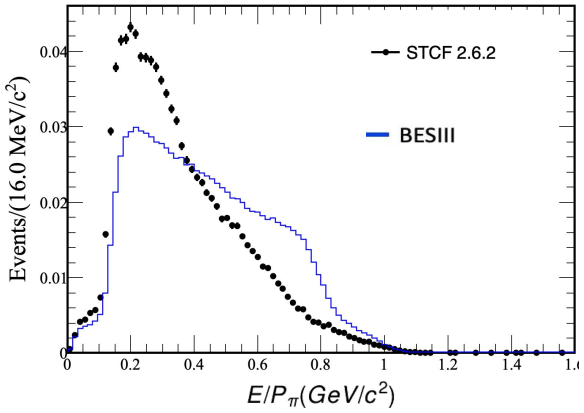
Compare STCF at $\sqrt{s}$ = 4.260 GeV with BESIII at $\sqrt{s}$ = 4.270 GeV

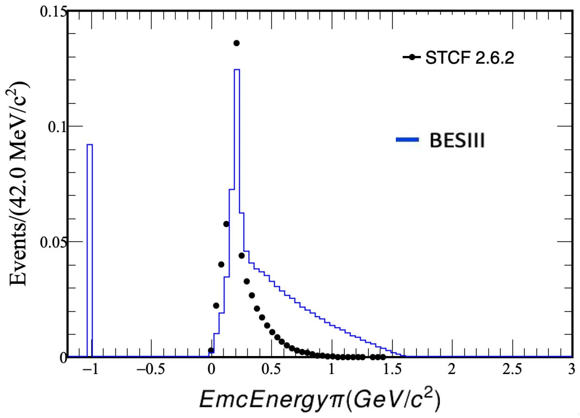


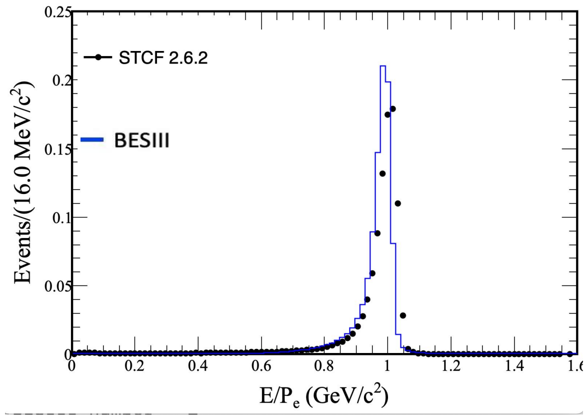


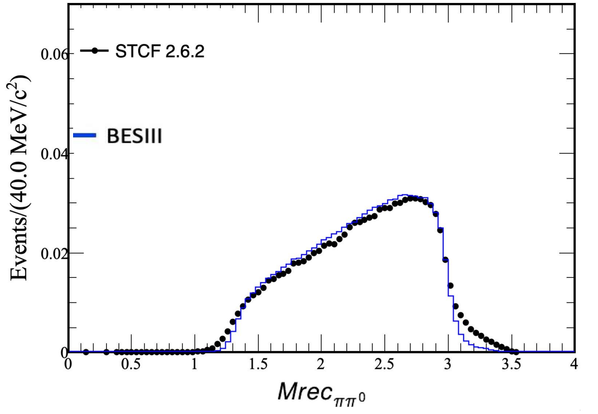






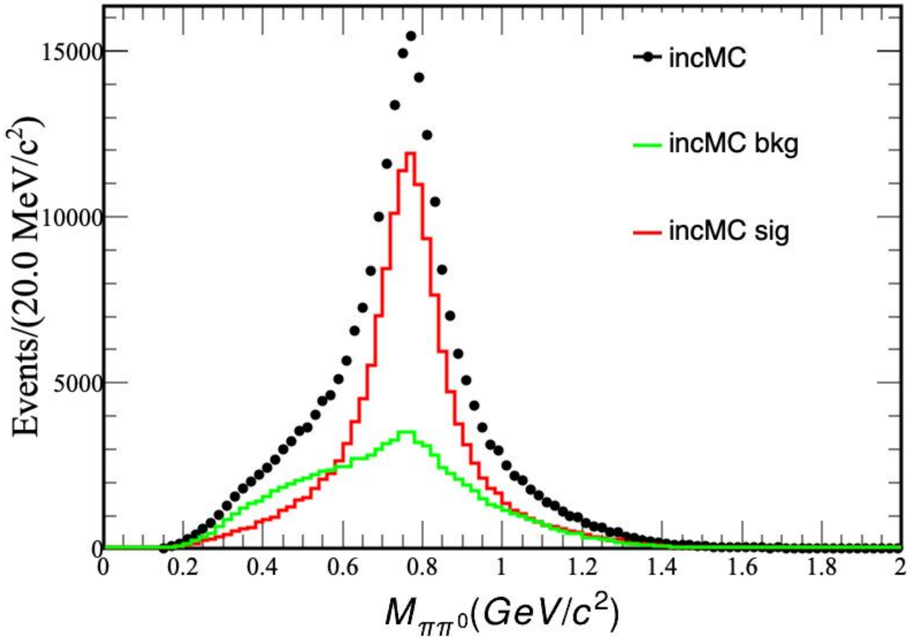




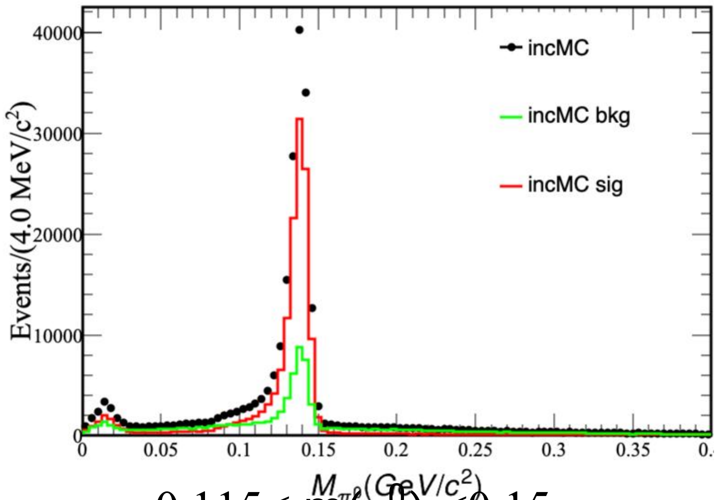


Signal selection criteria

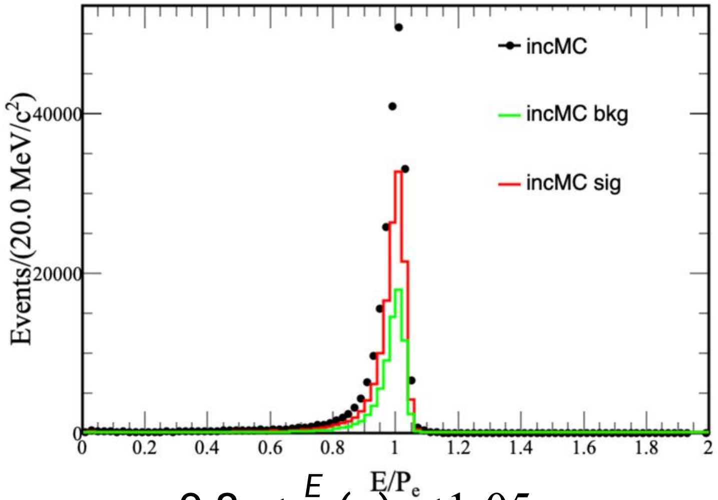
At $\sqrt{s}$ = 4.26 GeV, $\mathrm{m}(\pi^+\pi^0)$ is used to identify semileptonic decay, combined tag and signal selection .



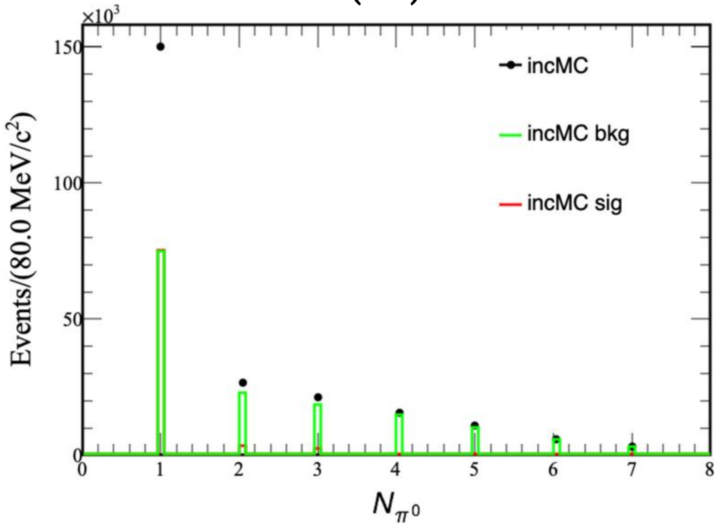
Event selection



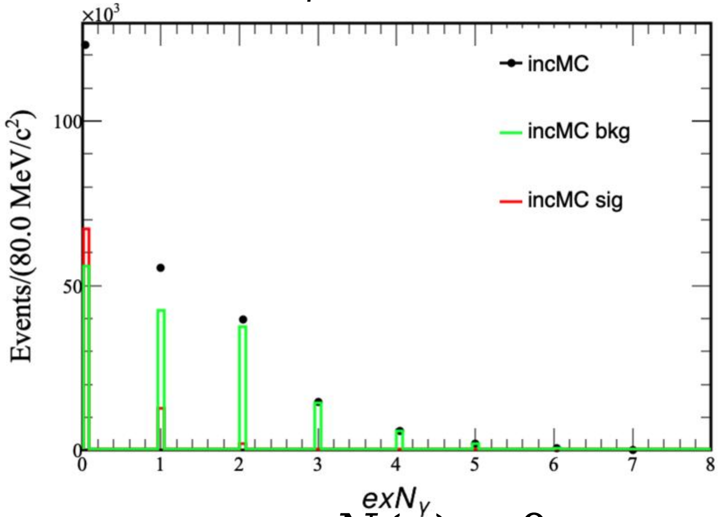
0.115< $m(\pi^0)$ <0.15



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

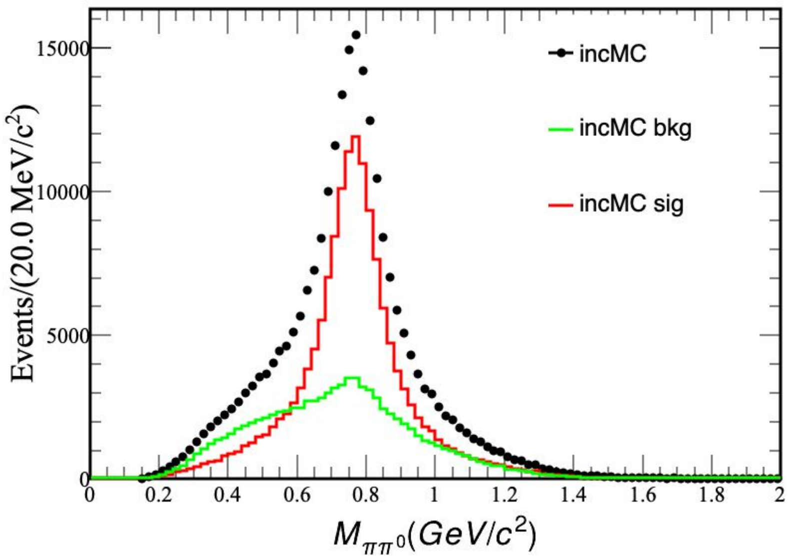


$N(\pi^0)$=1

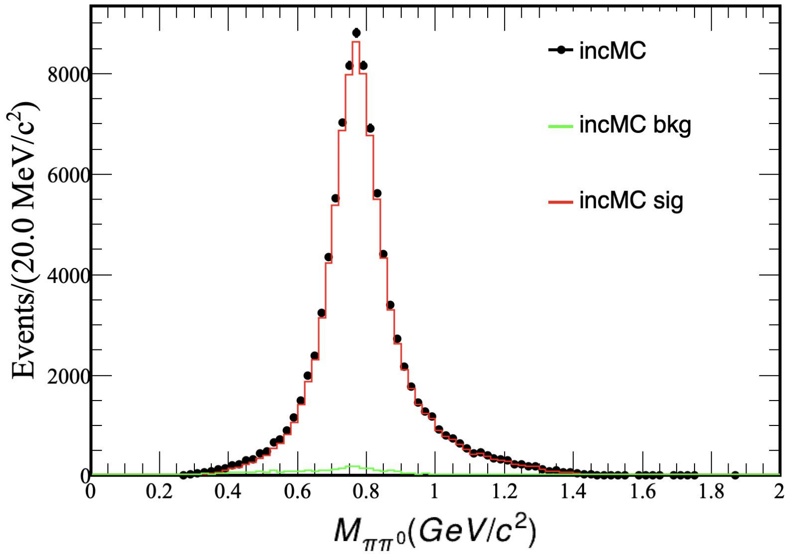


$exN(\gamma) = 0$

Signal selection criteria



$0.115 < m(\pi^0) < 0.15$,
$0.8 < \frac{E}{P}(e) < 1.05$,
$N(\pi^0)=1$, $exN(\gamma) = 0$



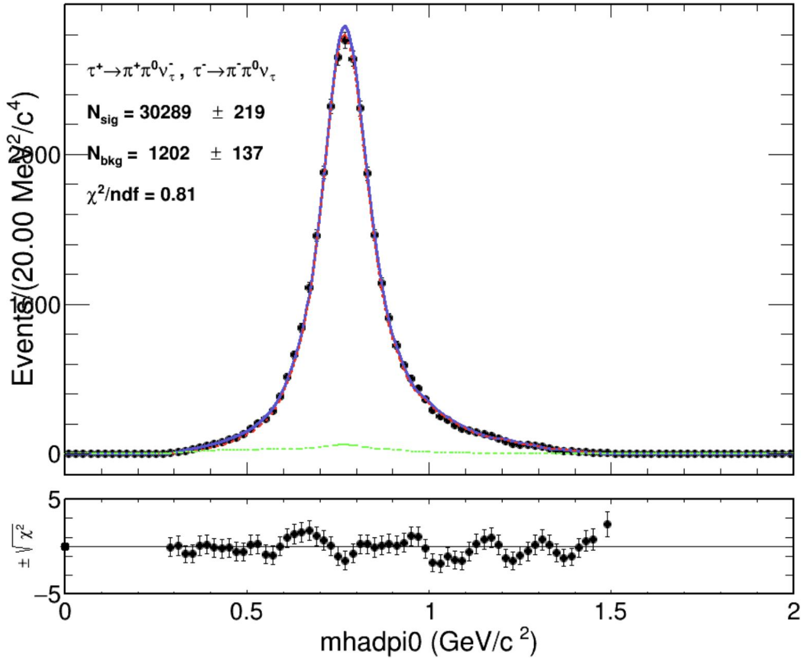
Event selection

	ditau sigMC num	Efficiency	BESIII efficiency	ditau bkgMC num	bkg ratio
No cut	151492	55.7%	48.3%	90351	37.4%
0.115< $m(\pi^0)$ <0.15	116461	42.8%	45.0%	35756	23.5%
$0.8 < \frac{E}{P}(e) < 1.05$	100881	37.1%	40.8%	28160	21.8%
$N(\pi^0)$ =1， $exN(\gamma) = 0$	92117	33.9%	31.1%	3350	3.5%

Signal Fit

$\sqrt{s}$= 4.260 GeV

- Signal shape: From 2,000,000 ditau inclusive MC;
- Background shape: From 2,000,000 ditau inclusive MC;
- Data:1,000,000 ditau inclusive MC serve as data.



Calculation details

- $B(\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau) = \frac{N_{\rm sig}}{2N_{\tau\tau}\varepsilon B(\tau^-\to e^-\nu_\tau\overline{\nu}_{\boldsymbol{e}}) g B(\pi^0\to\gamma\gamma/K^0_S\to\pi^+\pi^-)}$

- $input\ sys. = B(\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau) \times \sqrt{\left(\frac{B(\tau^-\to e^-\nu_\tau\overline{\nu}_{\boldsymbol{e}})_{err}}{B(\tau^-\to e^-\nu_\tau\overline{\nu}_{\boldsymbol{e}})}\right)^2 + \left(\frac{B(\pi^0\to\gamma\gamma/K^0_S\to\pi^+\pi^-)_{err}}{B(\pi^0\to\gamma\gamma/K^0_S\to\pi^+\pi^-)}\right)^2}$

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

Parameter	value
$B_{\rm tag}$	0.1782 ± 0.0004
$\mathrm{B}(\pi^0 \to \gamma\gamma)$	0.9880 ± 0.00034
$B(K^0_S \to \pi^+\pi^-)$	0.6920 ± 0.0005

Measurement result

	data volume	Bf(%)	stat.	input sys./sys.
Our work (4.260 GeV)	1,000,000 MC	25.39	0.21(0.83%)	0.06(0.24%)
	Estimated cumulative retrieval 1ab^{-1}	25.39	0.0036(0.01%)	0.06(0.24%)
ALEP	--	25.47	0.097(0.38%)	0.085(0.33%)
Belle	--	25.24	0.01(0.04%)	0.39(1.55%)

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

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: Global PID

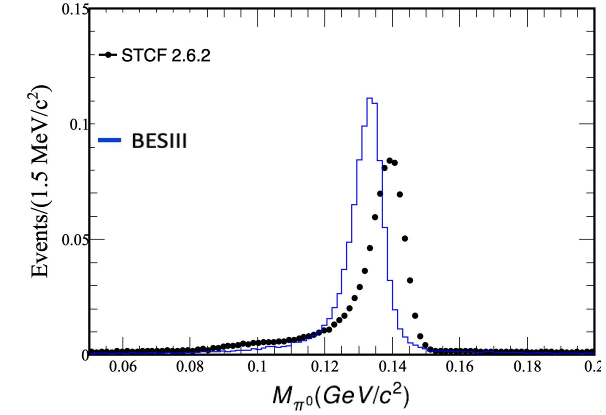
  e :$Prob_e$>$Prob_\pi$;$Prob_e > Prob_K$;

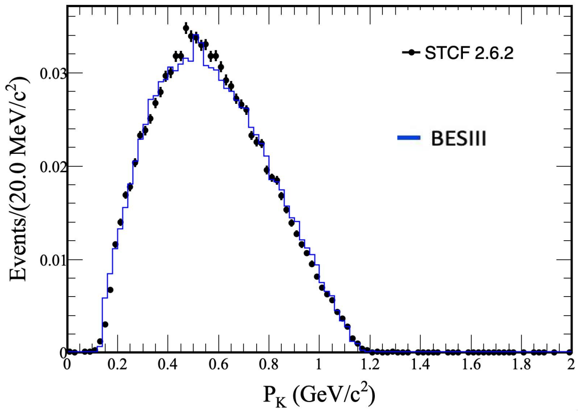
  K :$Prob_K$>$Prob_e$;$Prob_K > Prob_\pi$;

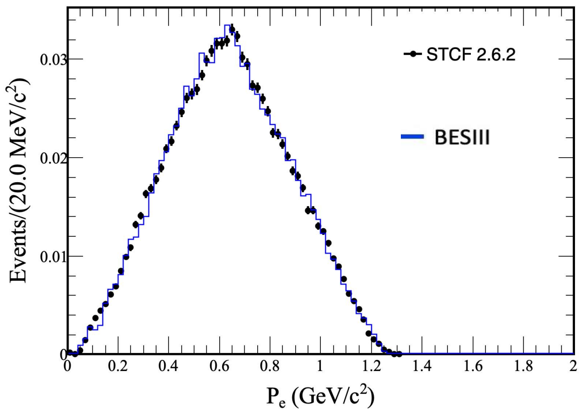
  N_K =1, $N_e = 1$

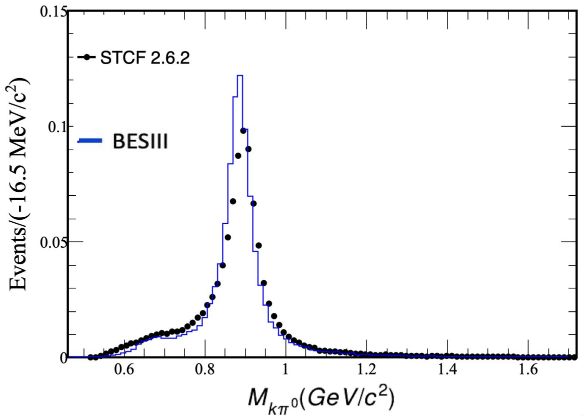
Comparison chart

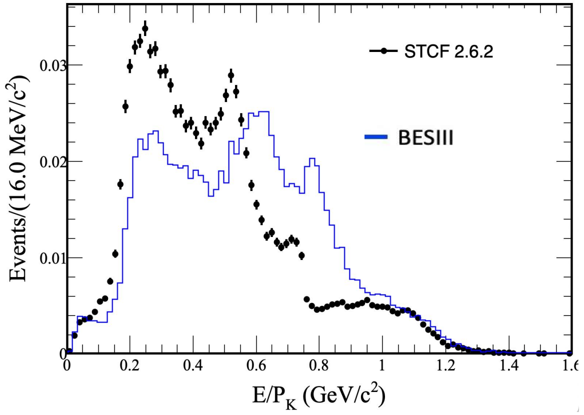
Compare with BESIII at $\sqrt{s}$ = 3.773 GeV

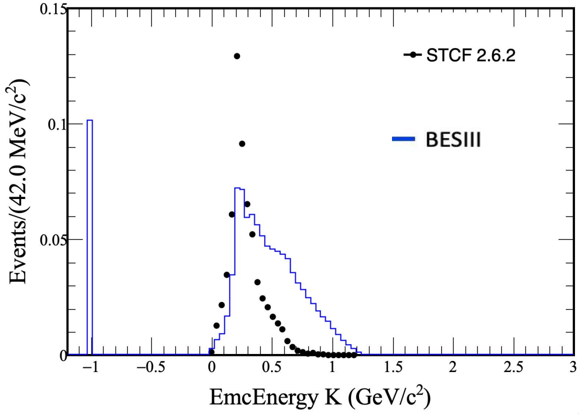


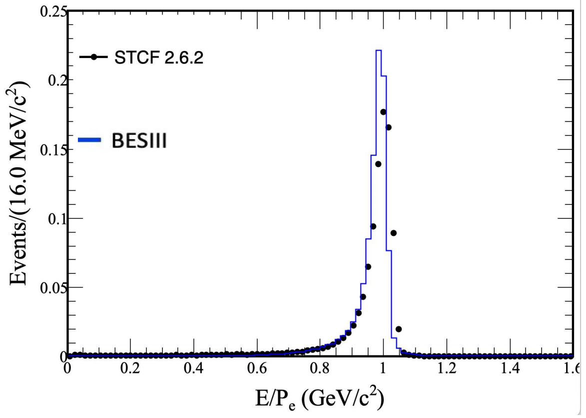


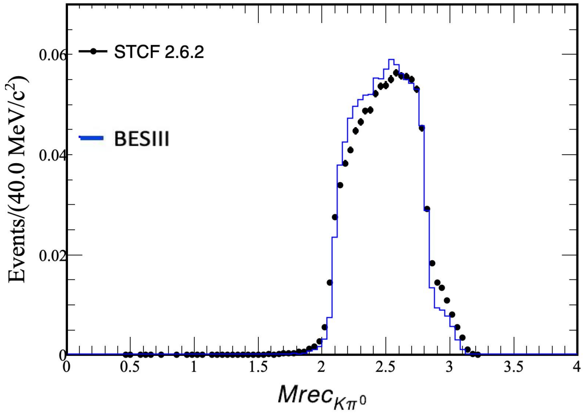






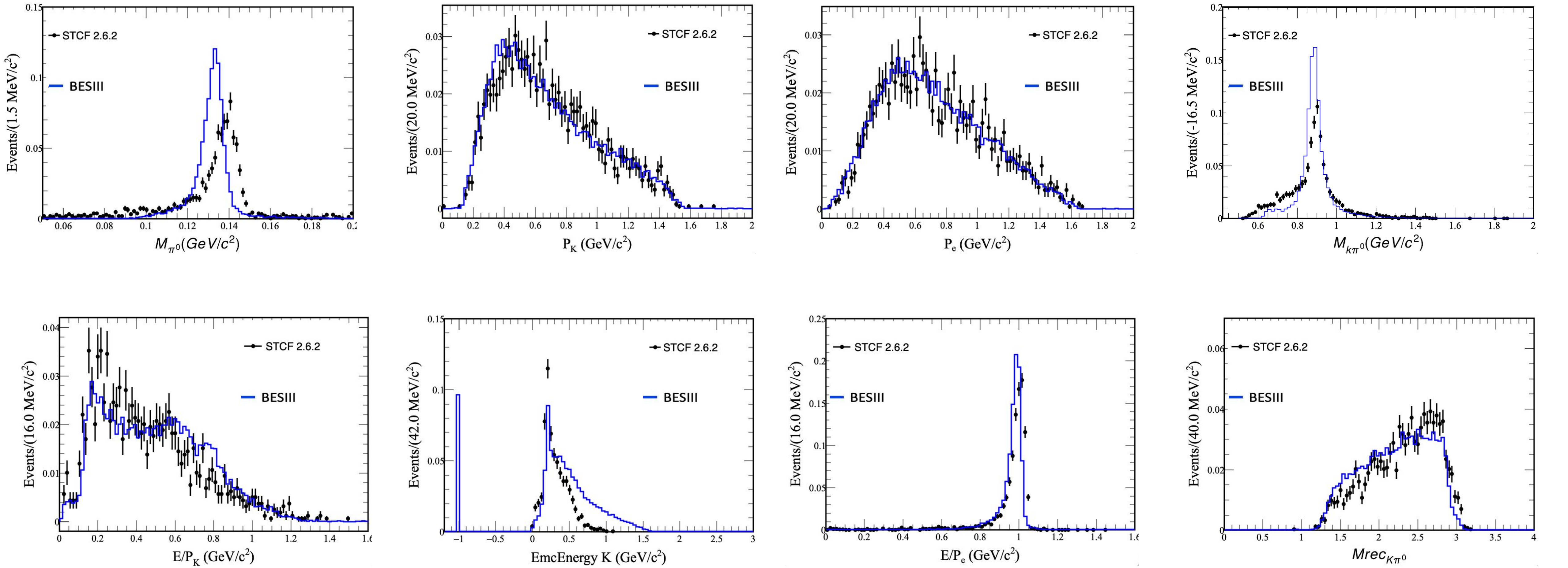






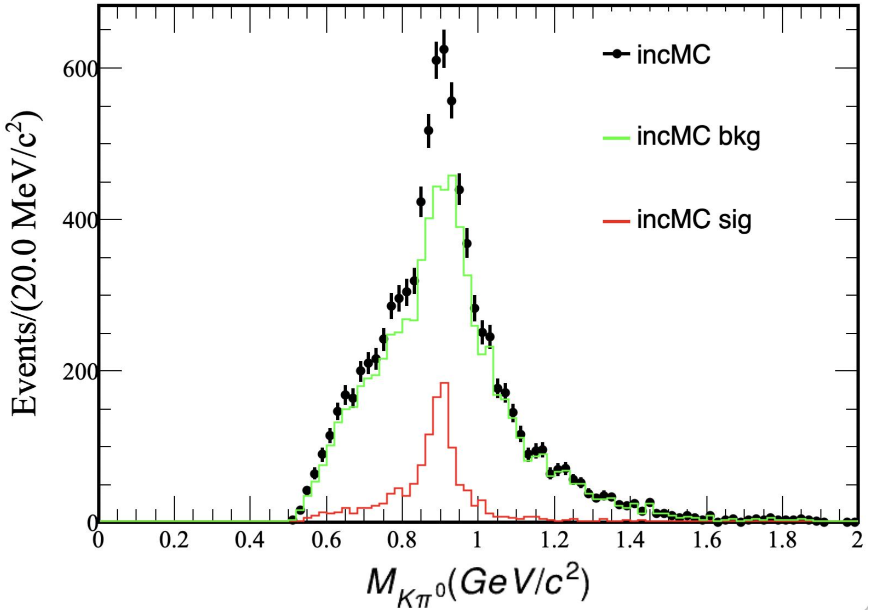
Comparison chart

Compare STCF at $\sqrt{s}$ = 4.260 GeV with BESIII at $\sqrt{s}$ = 4.270 GeV



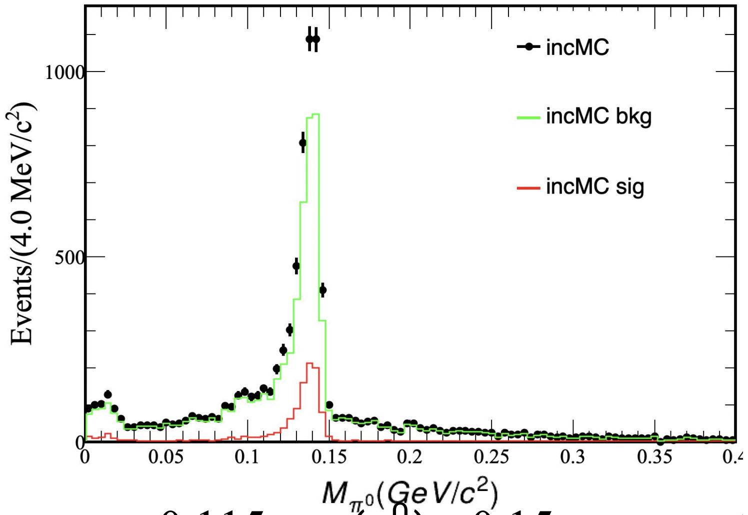
Signal selection criteria

At $\sqrt{s}$ = 4.26 GeV, $\mathrm{m}(\mathrm{K}^+\pi^0)$ is used to identify semileptonic decay, combined tag and signal selection

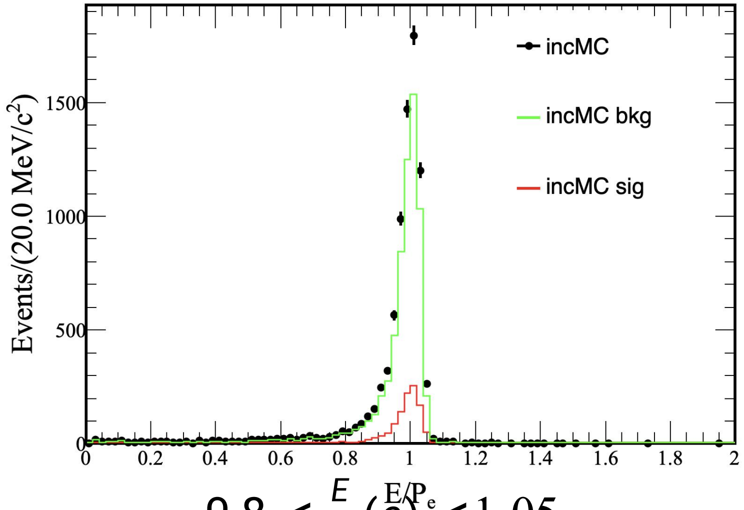


Event selection

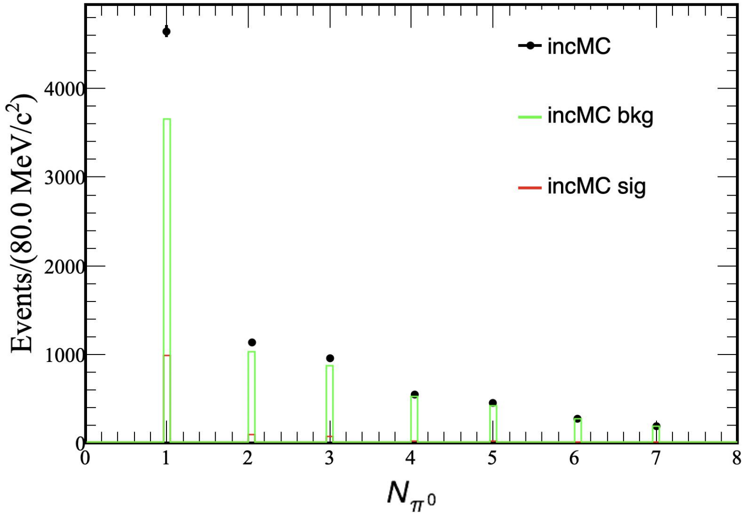
$\sqrt{s} = 4.260$ GeV



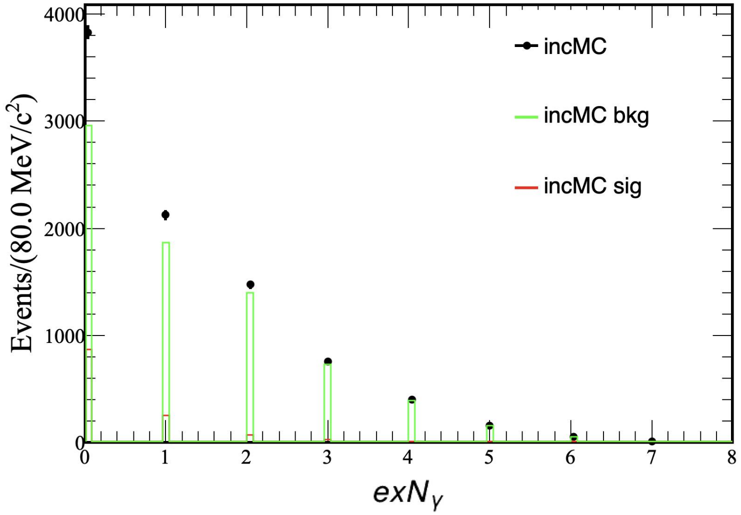
$0.115 < m(\pi^0) < 0.15$



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

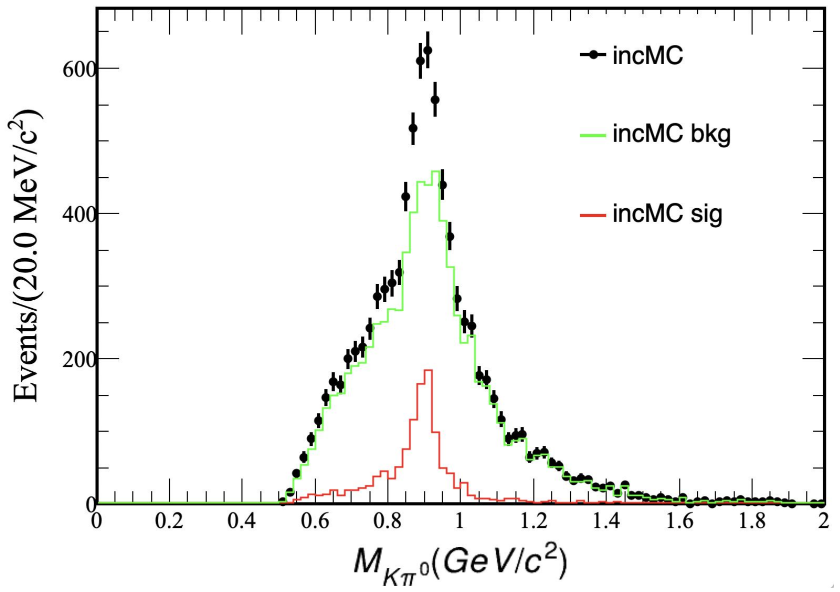


$N(\pi^0)=1$



$exN(\gamma) = 0$

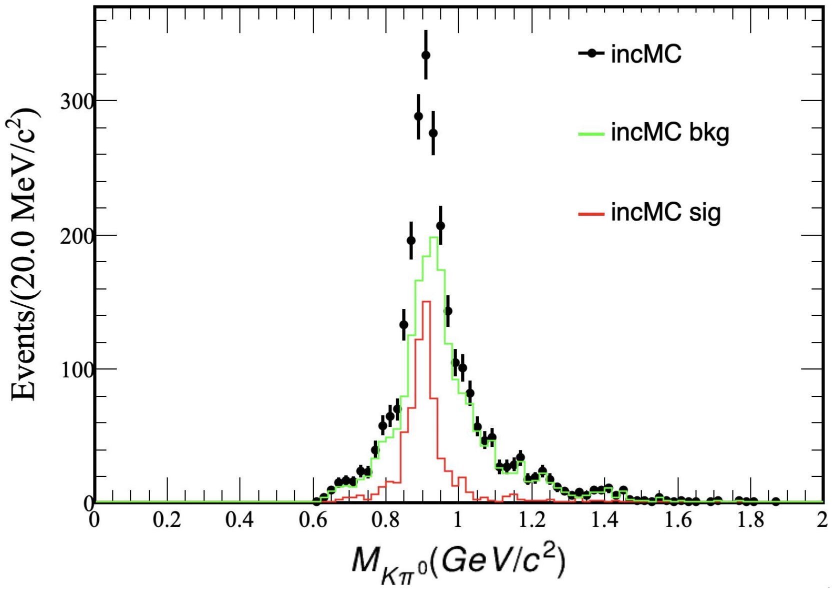
Signal selection criteria



$0.12 < m(\pi^0) < 0.15$,

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

$N(\pi^0)=1$, $exN(\gamma) = 0$



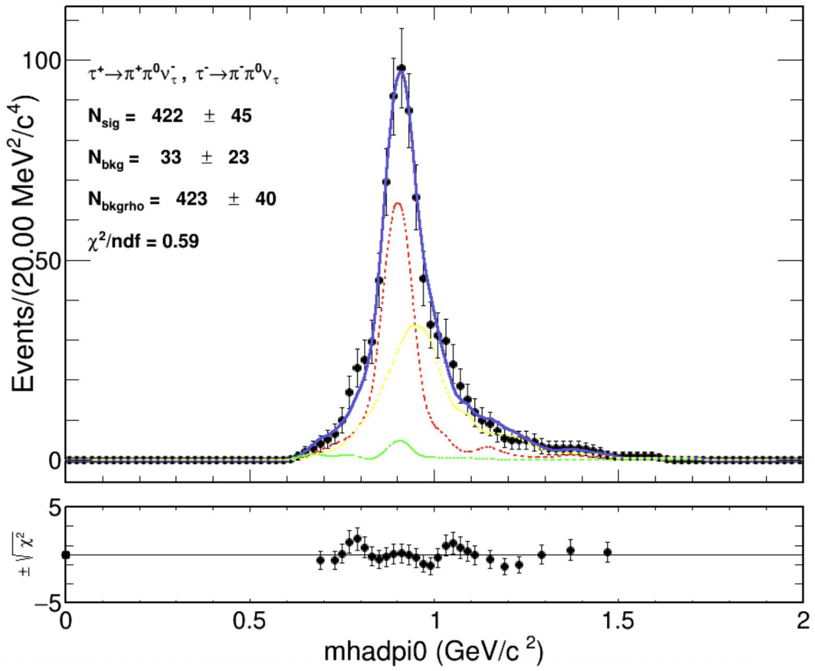
Event selection

	ditau sigMC num	Efficiency	BESIII efficiency	ditau bkgMC num	bkg ratio
No cut	1233	37.59%	41.7%	7560	85.98%
0.115< $m(\pi^0)$ <0.15	892	24.07%	37.9%	3805	81.01%
$0.8 < \frac{E}{P}(e) < 1.05$	781	20.92%	34.3%	3173	80.25%
$N(\pi^0)$ =1， $exN(\gamma) = 0$	689	16.86%	22.3%	1983	74.21%

Signal Fit

$\sqrt{s}$= 4.260 GeV

- Signal shape: From 2,000,000 ditau inclusive MC;
- Background shape: From 2,000,000 ditau inclusive MC;
- Data:1,000,000 ditau inclusive MC serve as data.



Measurement result

	data volume	Bf(10^{-3})	stat.	input sys./sys.
Our work (4.260GeV)	1,000,000 MC	2.91	0.32(11%)	0.006(0.21%)
	Estimated cumulative retrieval 1ab^{-1}	2.91	0.0054(0.19%)	0.006(0.21%)
BABR	––	4.16	0.03(0.72%)	0.18(4.33%)
ALEP	––	4.71	0.59(12.53%)	0.23(4.88%)
CLEO	––	4.44	0.26(5.86%)	0.24(5.41%)

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

Event selection

- **Charge tracks**

(Except for those decaying from K_S^0)

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

$\cos\theta$<0.93

- **PID requirement**

Using PID system: Global PID

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

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

(exclusion for those decaying from K_S^0)

$N_\pi = 1$, $N_e = 1$。

- **K_S^0 selection**

$|V_z| < 20$cm ; $\cos\theta < 0.93$

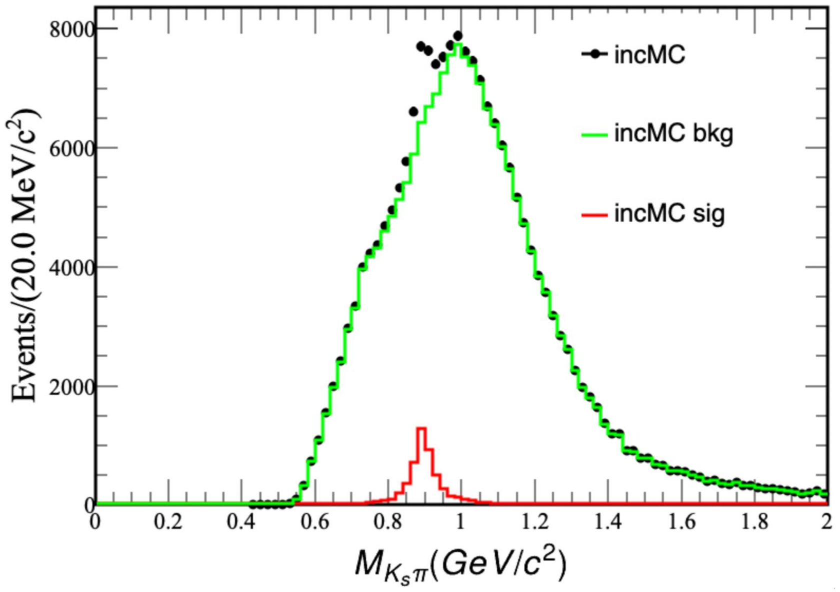
$0.4826 < M_{\pi^+\pi^-} < 0.5126$

χ^2<200 (Vertex Fitting)

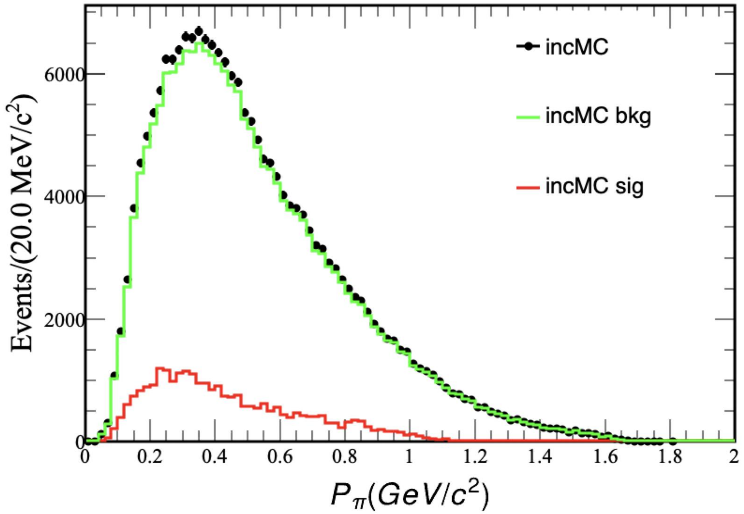
χ^2<200 (Secondary Vertex Fitting)

Signal selection criteria

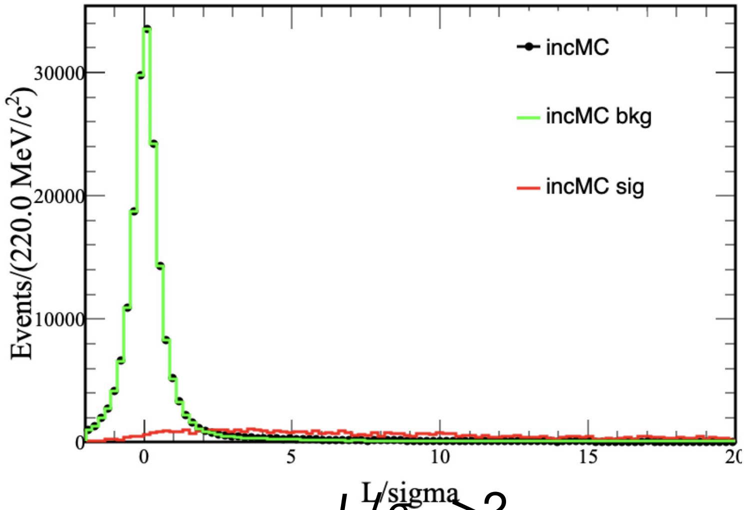
At $\sqrt{s}$ = 4.26 GeV, m($K_S\pi$) is used to identify semileptonic decay, combined tag and signal selection



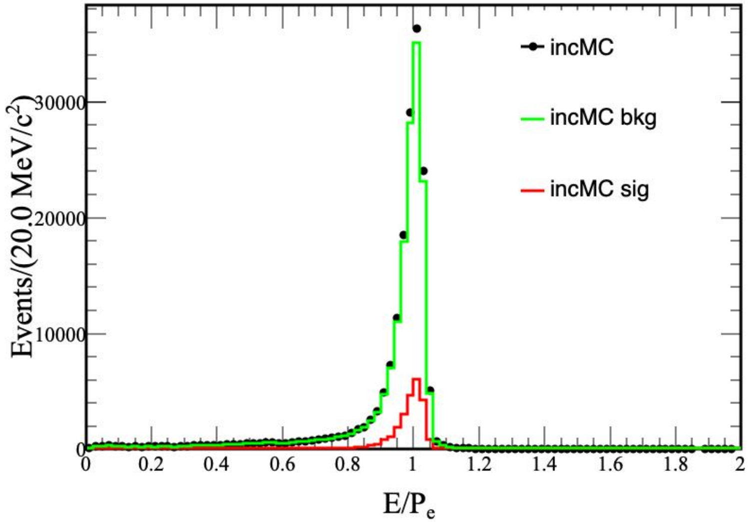
Event selection



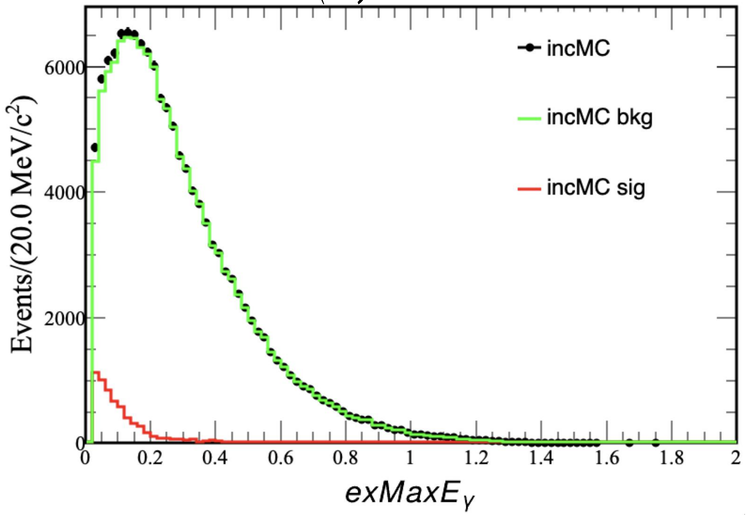
$P(\pi)$ <1.1



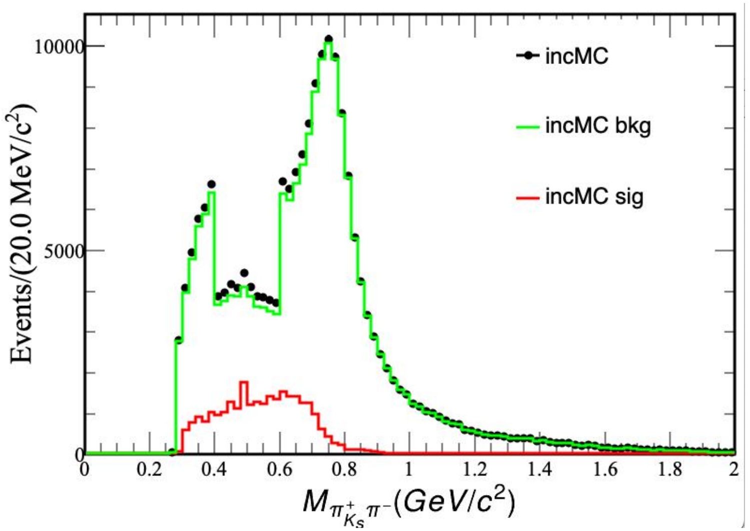
L/σ_L >2



E/P_e > 0.8

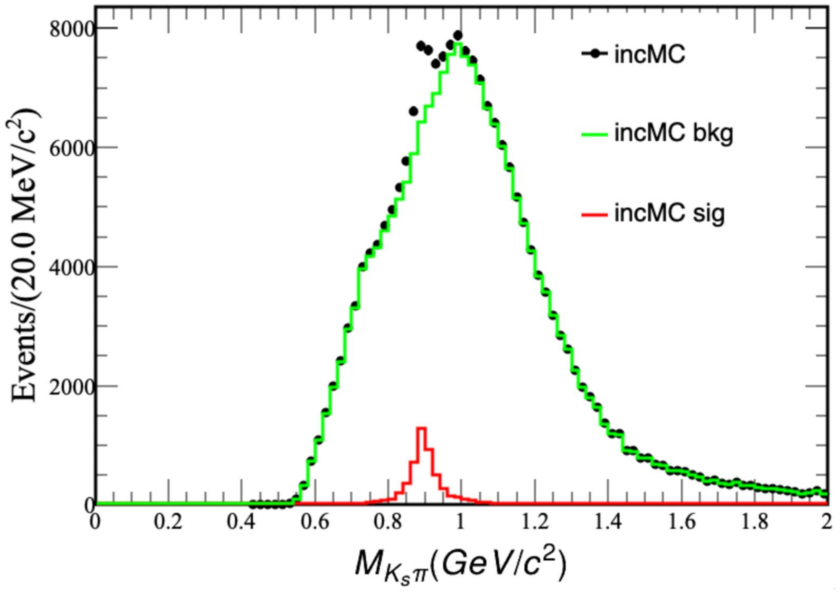


$exE(\gamma)_{max}$ < 0.2



$M(\pi^+_{K_S^0}\pi^-)$ < 0.8

Signal selection criteria

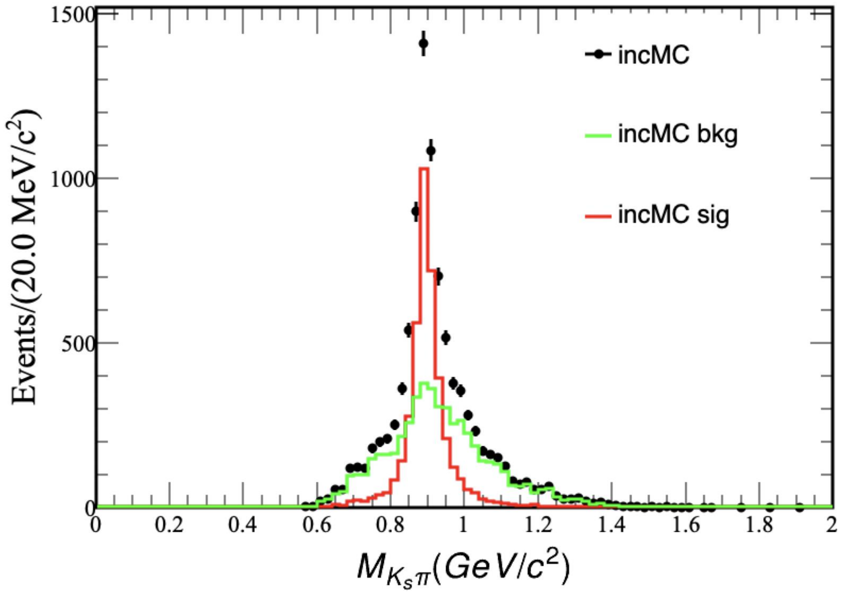


$P_\pi < 1.1$, $\frac{E}{P}(e) > 0.8$,

$L/\sigma_L > 2$,

$exE(\gamma)_{max} < 0.1$,

$M(\pi^+_{K_S^0}\pi^-) \leq 0.8$



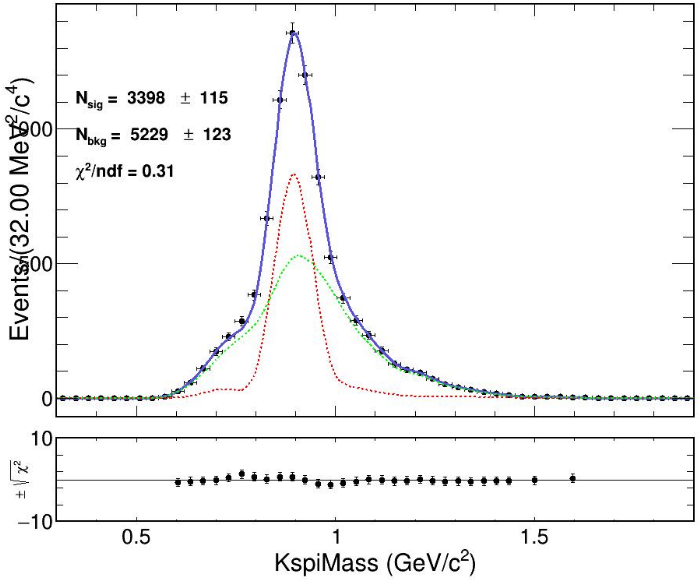
Event selection

		Signal MC		
Initial number of events		16603	Cut efficiency $\varepsilon(\%)$	Rest efficiency $\varepsilon(\%)$
After the algorithm		5498	33.11%	33.11%
Further event selection	$P_\pi < 1.1\mathrm{GeV}/c$	5464	99.38%	32.91%
	$\frac{E}{P}(e) > 0.8$	4869	89.11%	29.33%
	$L/\sigma_L > 2$	4349	89.32%	26.19%
	$exE(\gamma)_{max} < 0.2\mathrm{GeV}$	4249	97.70%	25.59%
	$M(\pi^+_{K_S^0}\pi^-) < 0.8\ \mathrm{GeV}/c^2$	4103	96.56%	24.71%

Signal Fit

$\sqrt{s}$= 4.260 GeV

- Signal shape: From ditau inclusive MC;
- Background shape: From ditau inclusive MC;
- Data: ditau inclusive MC serve as data.



Measurement result

	data volume	Bf(10^{-3})	stat.	input sys./sys.
Our work (4.260GeV)	11,000,000 MC	5.07	0.189(3.7%)	0.012(0.23%)
	Estimated cumulative retrieval 1ab^{-1}	5.07	0.0004(0.008%)	0.006(0.21%)
Belle	––	4.16	0.01(0.24%)	0.08(1.92%)

Summary

- We have measured the branching fractions of the decay $\tau^+ \to \pi^+\pi^0\overline{\nu}_\tau$, $\tau^+ \to K^+\pi^0\overline{\nu}_\tau$ and $\tau^+ \to K_S^0\pi^+\overline{\nu}_\tau$ at $\sqrt{s}$ = 4.26 GeV.
- We have also compared the performances and efficiencies between STCF and BESIII at $\sqrt{s}$ = 3.773 GeV and $\sqrt{s}$ = 4.26 GeV. Apart from significant differences in the distributions of $\mathrm{m}(\pi^0)$, $E/P(hadron)$, and the EMC energy of hadron , the distributions of other variables are relatively similar.

Next to do

- To use more MC samples.
- To estimate the strong coupling constant and CPV .