Tau physics at BESIII

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Workshop of tau physics at BELLE II and STCF
2026.8.30-9.2

Outline

- Introduction
- BEPCII and BESIII
- Interesting topics at BESIII
  - Tau mass measurement
  - Study of Br($\psi(3686) \rightarrow \tau^- \tau^+$)
  - Measurement of α_s
  - Study of $\tau^- \rightarrow \pi^- \pi^0 \nu_{\tau,}$
  - ……
- Summary

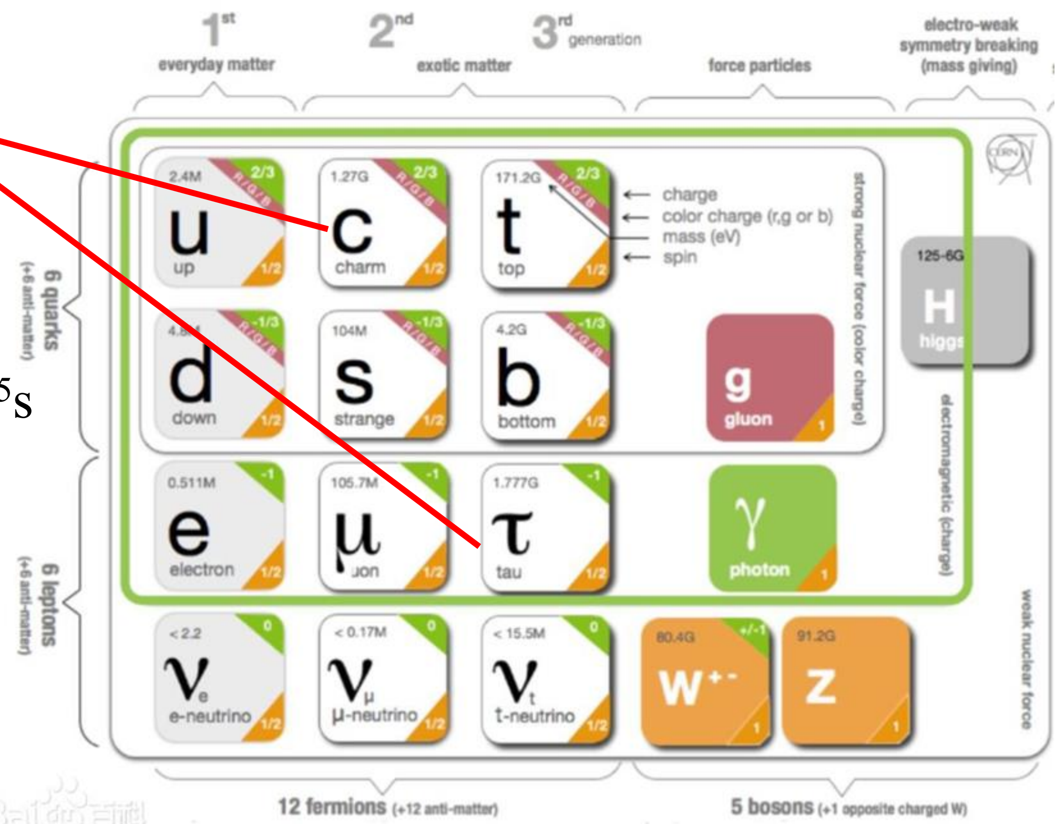
Introduction

BEPCII, BESIII

Found by MARKI in 1975

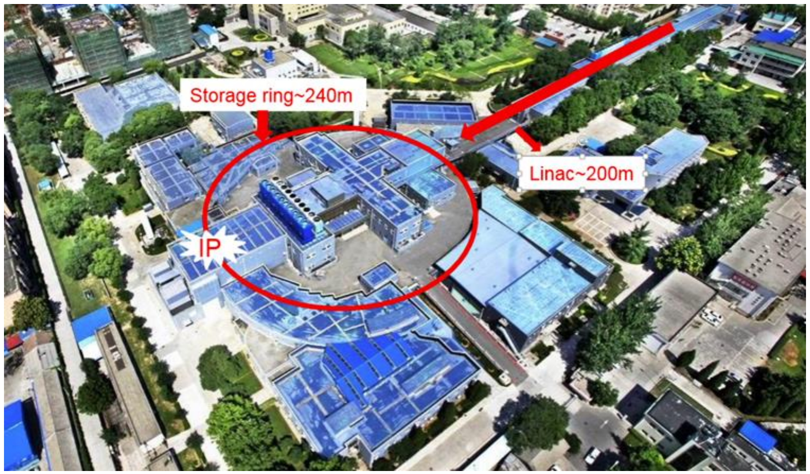
Mean life: $(290.3 \pm 0.5) \times 10^{-15}$s

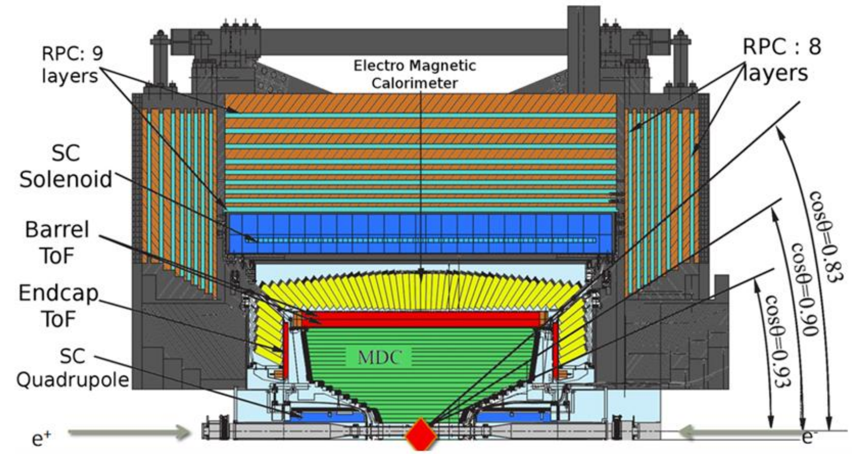
$m_{\tau} = 1776.93 \pm 0.09$ MeV

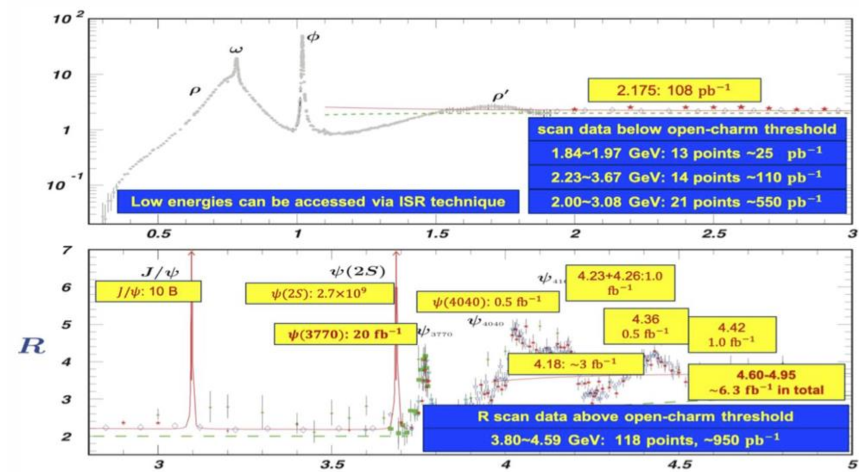


- The heaviest lepton
- Provide plenty of tests to standard model

BEPCII & BESIII







BEPCII: $\sqrt{s}$ =(1.84−4.95/5.6) GeV

Peak luminosity: 1.1×10^{33} $cm^{-2}s^{-1}$ @3.773 GeV

BESIII: MDC: σP/P =0.5% @ 1 GeV; σdE/dx = 6%

TOF: σT = 68(60) ps for barrel (endcap);

EMC: σE/E =2.5%(5%) for barrel (endcap)

CGEM

About 50 fb data collected

Tau mass measurement

- Tau lepton mass is a foundamental parameter of the Standard Model

  $m_e = 0.5109989461 \pm 0.0000000031$ MeV (6.1×10^{-9}) ; PDG(2018)
  $m_\mu = 105.6583745 \pm 0.0000024$ MeV (2.3×10^{-8}) ;
  $m_\tau = 1776.93 \pm 0.09$ MeV (5.1×10^{-5})

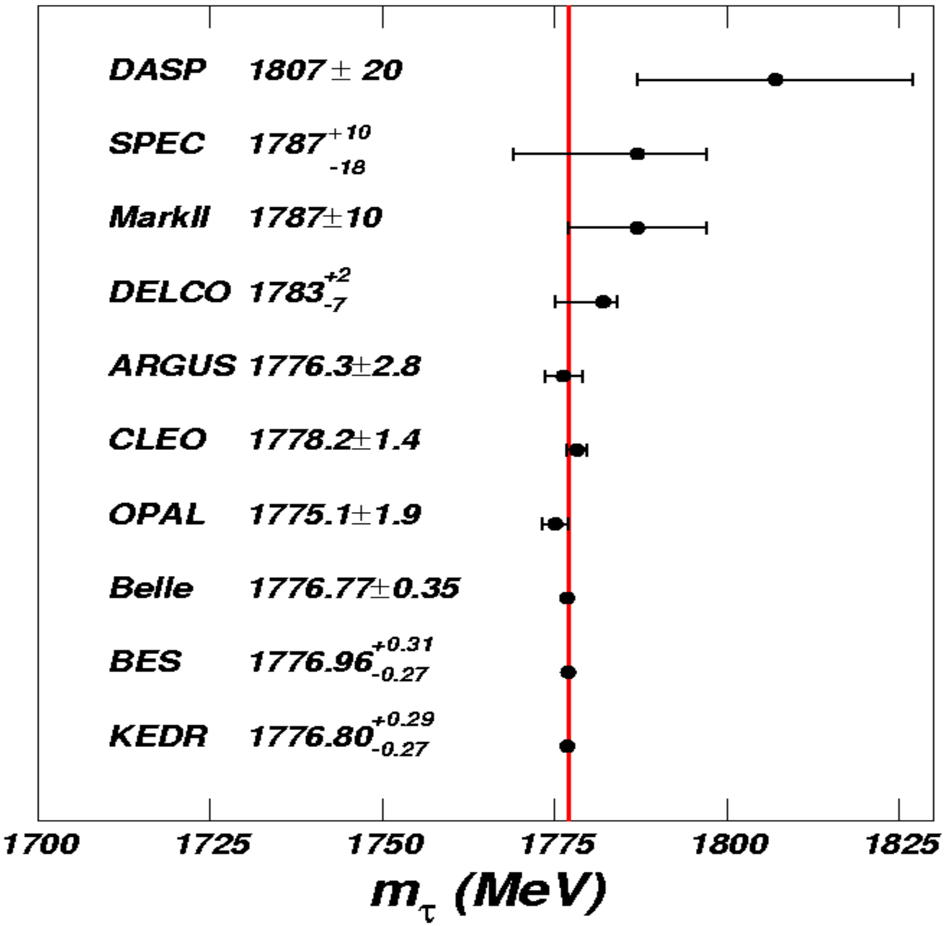
- Leptonic universality test

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\tau_\mu}{\tau_\tau}\left(\frac{m_\mu}{m_\tau}\right)^5 \frac{B(\tau \to e\nu_e\nu_\tau)}{B(\mu \to e\nu_e\nu_\mu)}\left(1+\Delta_e\right)$$

τ mass is sensitive to universality: m_τ^5

- Threshold scan method is used

Tau mass status



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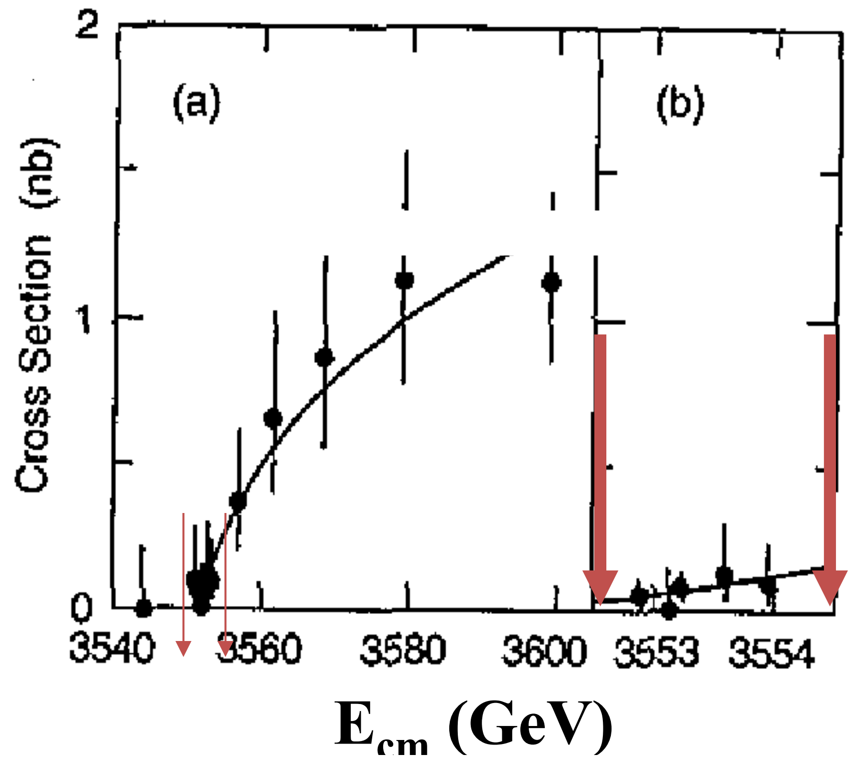
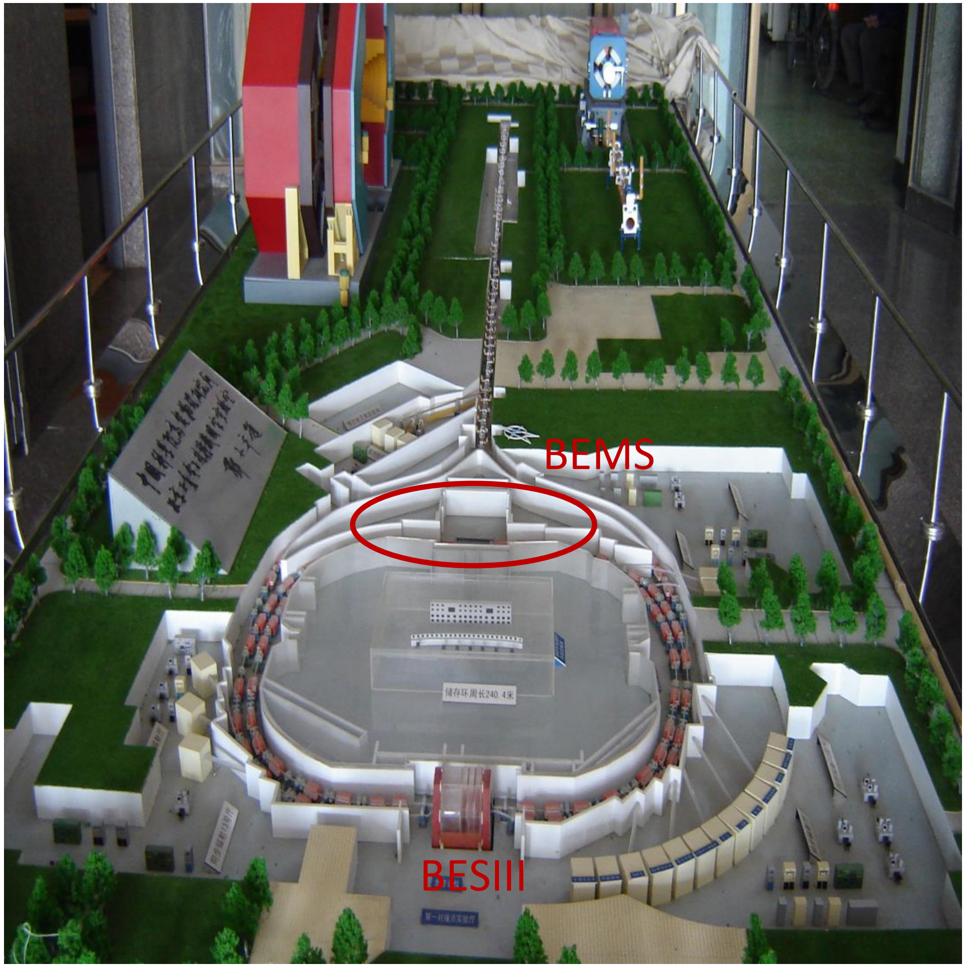
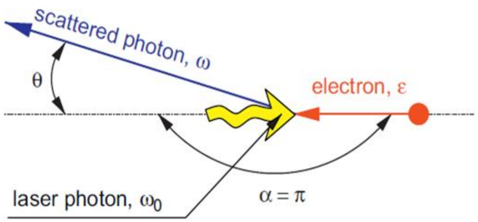


$$M_\tau = 1776.96\,^{+0.18}_{-0.21}\,^{+0.25}_{-0.17}\ \mathrm{MeV} \quad \delta M_\tau / M_\tau = 1.7\times10^{-4}$$

How to improve the statistical and systematic uncertainties?

Systematic uncertainty: BEMS@BEPCII





$$\omega_{max} = \frac{\varepsilon^2}{\varepsilon + m_e^2/4\omega_0^2},$$

$$\varepsilon = \frac{\omega_{max}}{2}\left[1 + \sqrt{1 + \frac{m_e^2}{\omega_0\omega_{max}}}\right].$$

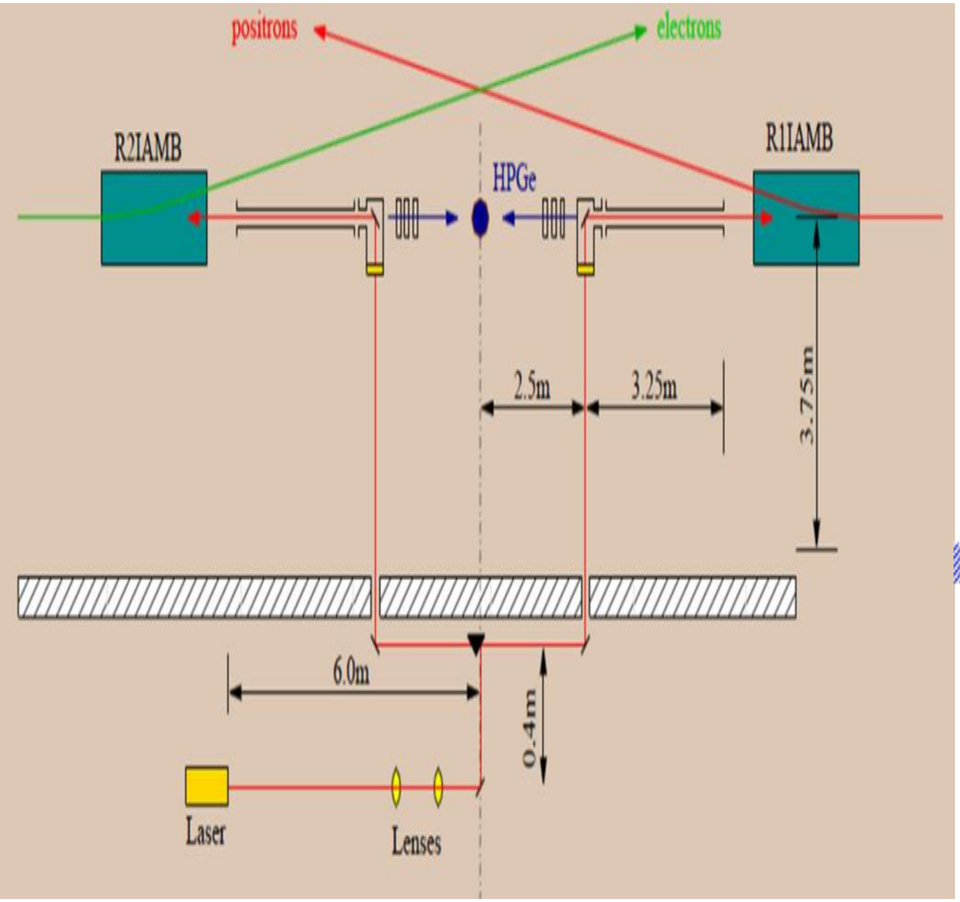
E_{beam}： 1 ~ 2.3 GeV

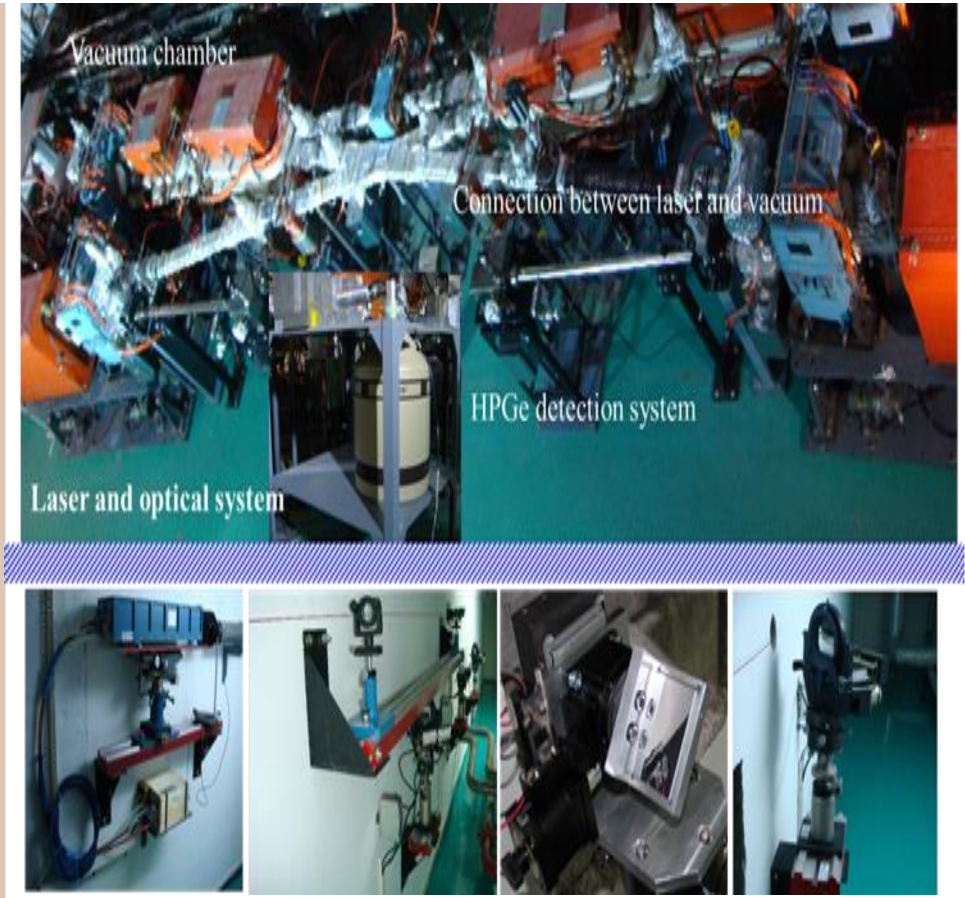
Co_2 Wave Length， 10.59 μm

ORTEC HPGe detector, ~30%

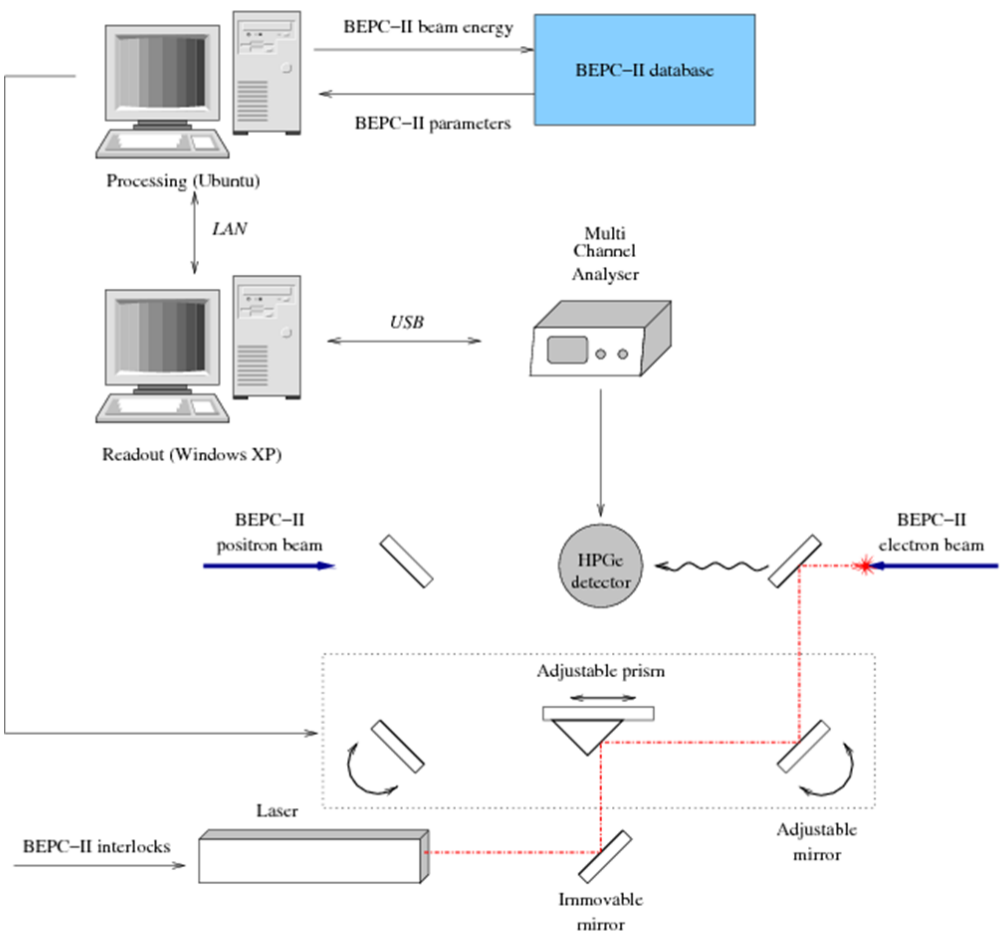
ORTEC Dspec Pro

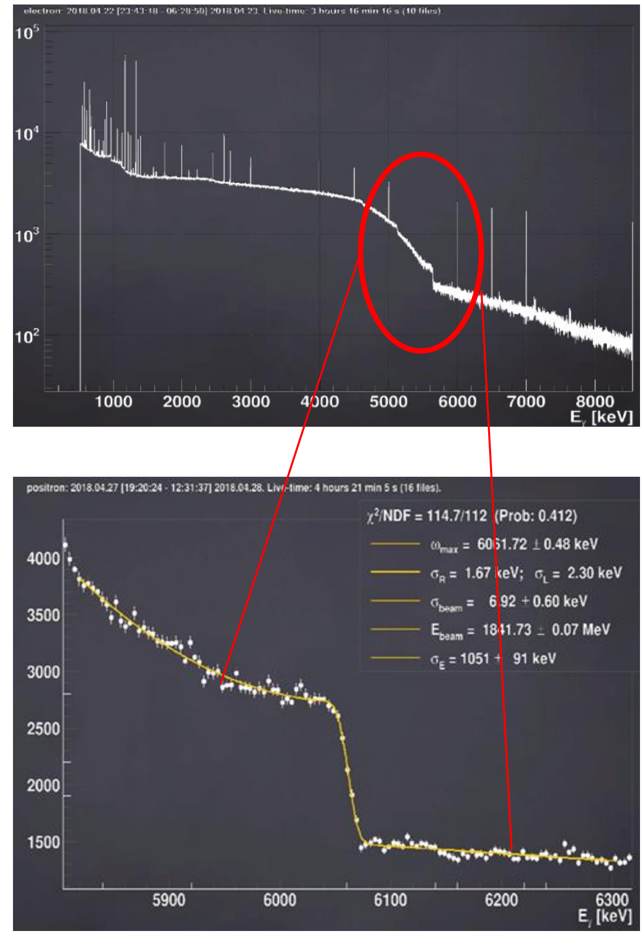
Beam energy measurement system (BEMS)





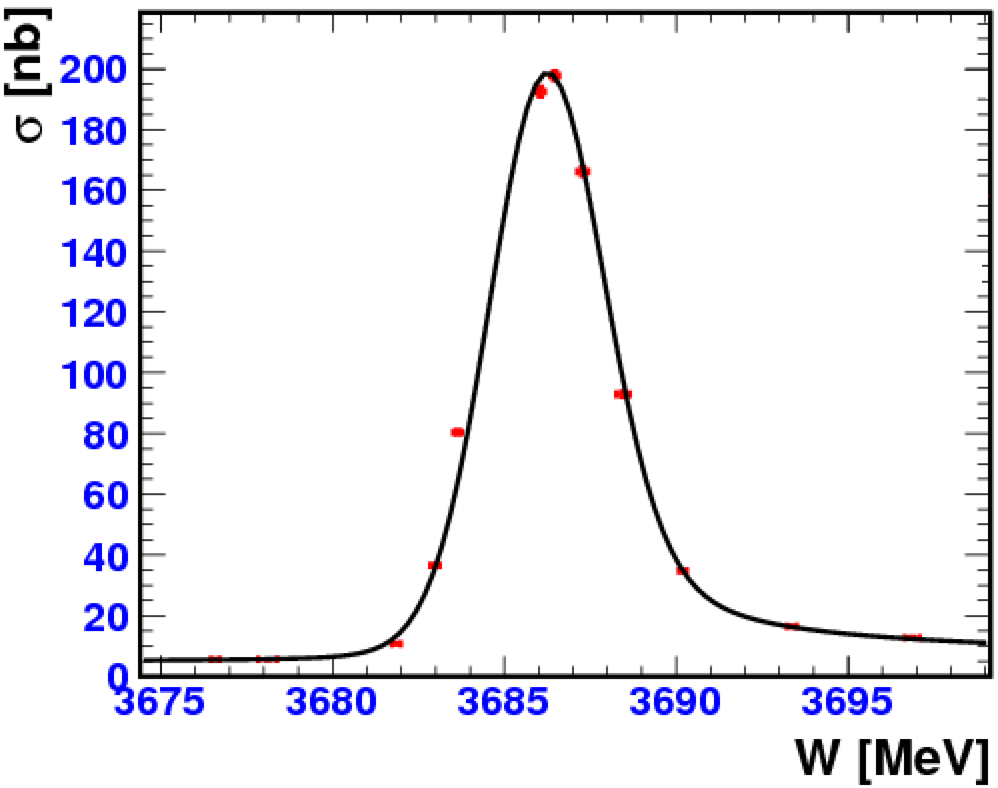
Control and edge fit





Performance of BEMS

The accuracy of beam energy measurement was studied by comparison of ψ(2s) resonance mass 3686.09 ± 0.040 MeV, with its value obtained using the energy obtained using BEMS data.



Two scans of ψ(2s) with integrated luminosity about 4 pb^{-1}.

Mass difference:

$$\Delta m = m - m_{\psi} = 0.02 \pm 0.05 MeV$$

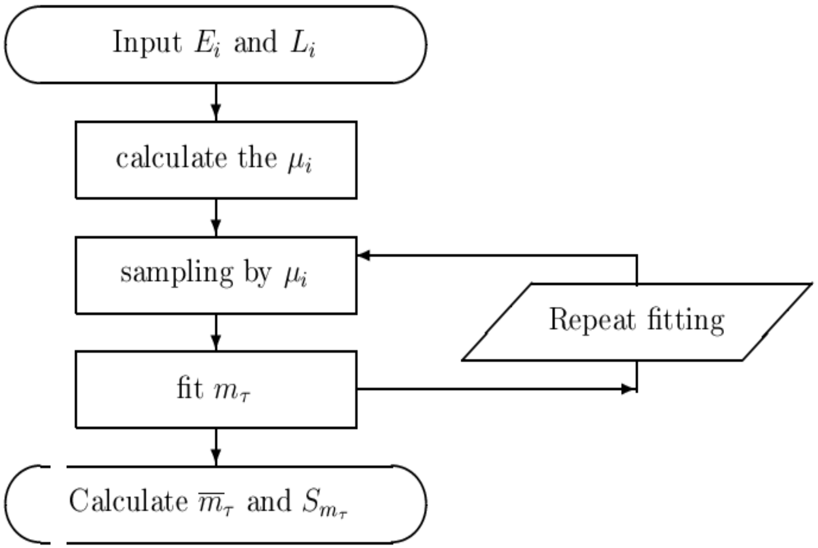
Deviation of the measured beam energy of the beam from true value:

$$\delta\varepsilon = \frac{\Delta m}{2} = 0.01 \pm 0.03$$

Accuracy of the beam energy measurement: **$\delta\varepsilon/\varepsilon \sim 2 \times 10^{-5}$**

Statistical optimization

$$\mu_i(m_\tau, s_i) = \mathcal{L}_i \cdot \left(\varepsilon \cdot \mathcal{B}_f \cdot \sigma_{obs}(m_\tau, s_i) + \sigma_{BG}\right)$$



Neglecting all experiment uncertainties

Luminosity $\mathcal{L}$;

Efficiency ε =*14.2%* ;

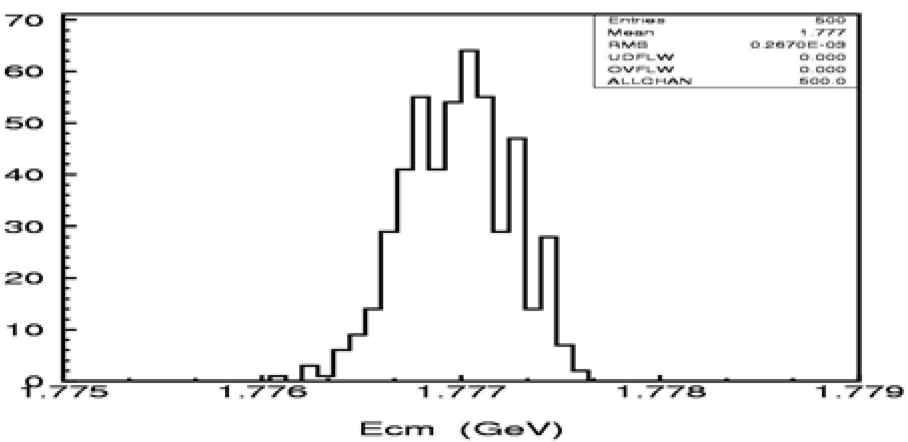
Branching fraction: $\mathcal{B}_f$ =2*0.1736 • 0.1784 ;

[$\mathcal{B}_f = \mathcal{B}_{\tau \to \mu\nu\nu} \bullet \mathcal{B}_{\tau \to e\nu\nu}$, **PDG06]**

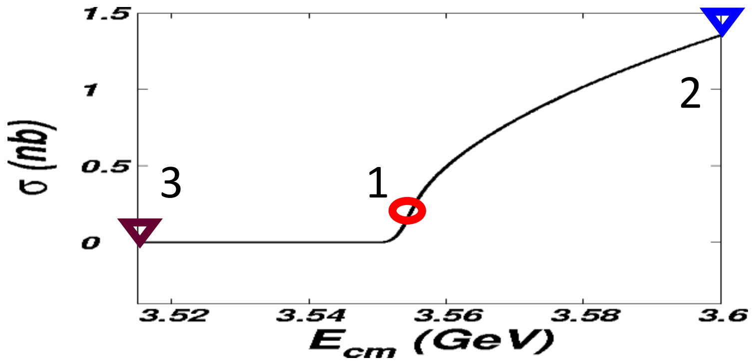
Assume : M_τ is known .

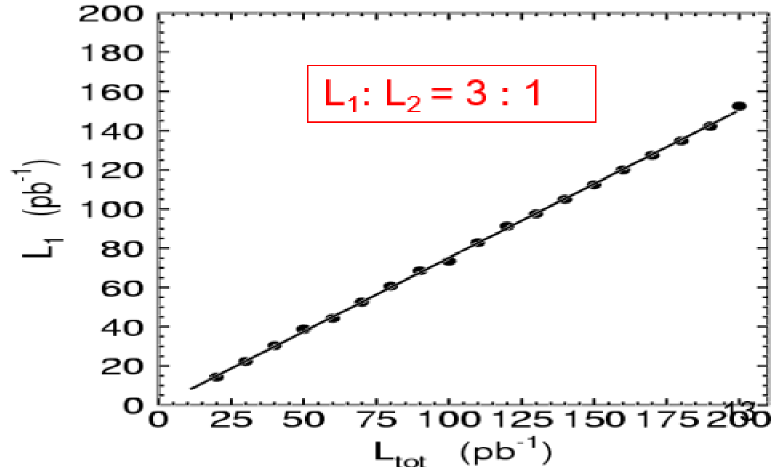
To find :

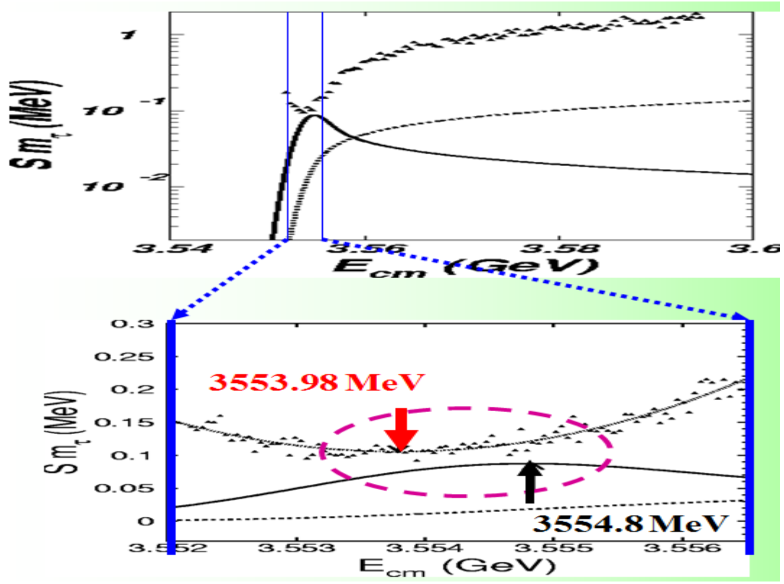
1. **Number of data taking point;**
2. **Distribution or position of data taking points;**
3. **Relation between luminosity and precision.**

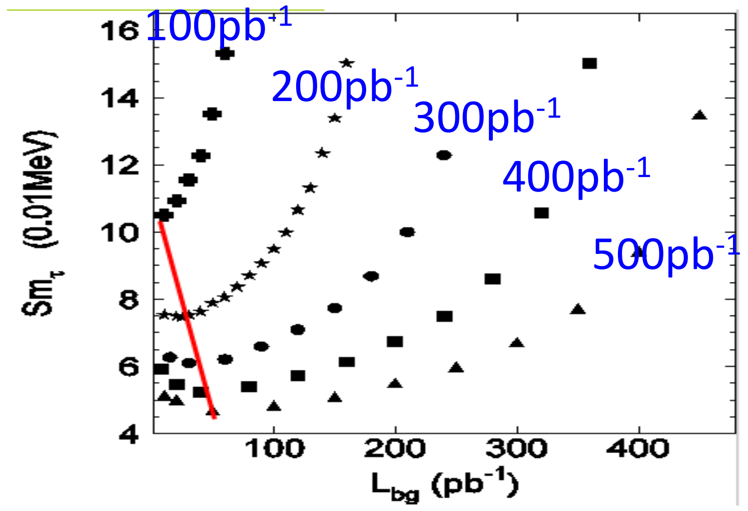


Statistical optimization









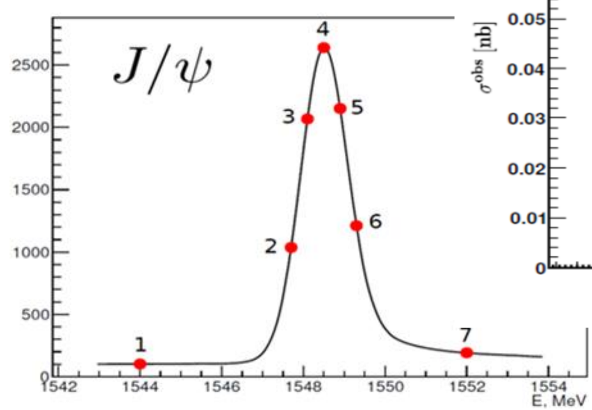
$L_3 \sim 10\% L_{tot}$

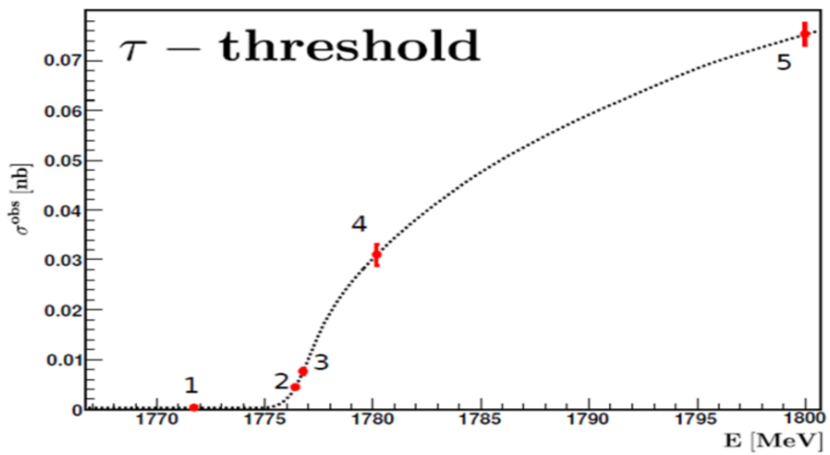
Data taking scenario

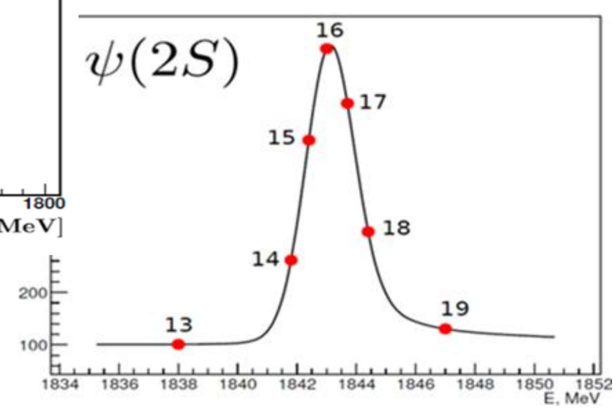
Three stages:

- J/ψ scan, 7 points, determine $M_{J/\psi}$ and σ_E
- Tau mass threshold scan
- ψ' scan, 7 points, determine $M_{\psi'}$ and σ_E

Total lum. ~100pb^{-1}, uncertainty: 0.1MeV







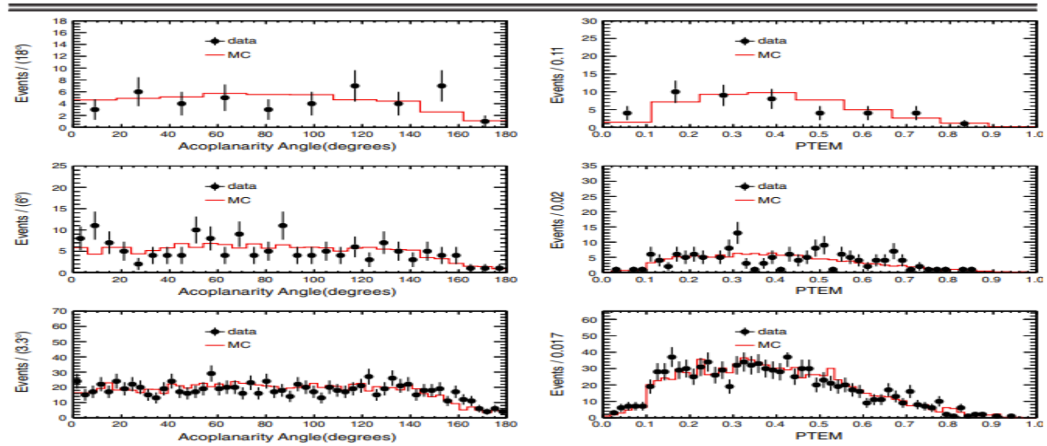
points	ΔE_1	ΔE_2	ΔE_3	ΔE_4	ΔE_5
ΔE_i/MeV	-5	-0.325	$+0.075$	$+3.5$	$+15$
$L_i\%$	14	39	26	7	14

$\Delta E_i = E_i - M_\tau$

Tau mass measurement in 2014

Scan	$E_{\rm CM}$ (MeV)	$\mathcal{L}(\rm nb^{-1})$
J/ψ	3088.7	78.5 ± 1.9
	3095.3	219.3 ± 3.1
	3096.7	243.1 ± 3.3
	3097.6	206.5 ± 3.1
	3098.3	223.5 ± 3.2
	3098.8	216.9 ± 3.1
	3103.9	317.3 ± 3.8
τ	3542.4	4252.1 ± 18.9
	3553.8	5566.7 ± 22.8
	3561.1	3889.2 ± 17.9
	3600.2	9553.0 ± 33.8
ψ'	3675.9	787.0 ± 7.2
	3683.7	823.1 ± 7.4
	3685.1	832.4 ± 7.5
	3686.3	1184.3 ± 9.1
	3687.6	1660.7 ± 11.0
	3688.8	767.7 ± 7.2
	3693.5	1470.8 ± 10.3

	1		2		3		4		Total	
Final state	Data	MC	Data	MC	Data	MC	Data	MC	Data	MC
ee	0	0	4	3.7	13	12.2	84	76.1	101	92.0
$e\mu$	0	0	8	9.1	35	31.4	168	192.6	211	233.1
$e\pi$	0	0	8	8.6	33	29.7	202	184.4	243	222.6
eK	0	0	0	0.5	2	1.8	16	16.9	18	19.3
$\mu\mu$	0	0	2	2.9	8	9.2	49	56.3	59	68.4
$\mu\pi$	0	0	4	3.9	11	14.1	89	86.7	104	104.7
μK	0	0	0	0.2	3	0.8	7	9.0	10	10.1
$\pi\pi$	0	0	1	2.0	5	7.7	57	54.0	63	63.8
πK	0	0	1	0.3	0	0.8	10	8.2	11	9.3
KK	0	0	0	0.0	1	0.1	1	0.3	2	0.4
$e\rho$	0	0	3	6.1	19	20.6	142	132.0	164	158.7
$\mu\rho$	0	0	8	3.3	8	11.8	52	63.3	68	78.5
$\pi\rho$	0	0	5	3.4	15	10.8	97	96.0	117	110.2
Total	0	0	44	44.2	153	151.2	974	975.7	1171	1171.0



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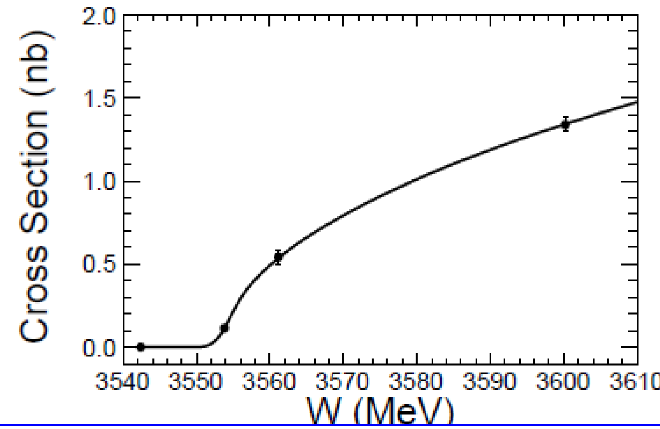
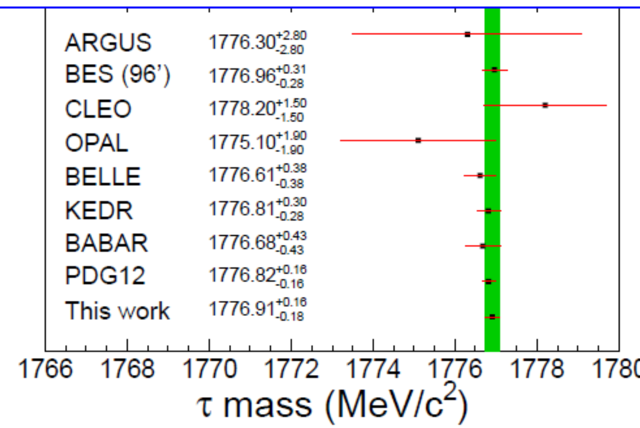


$$m_\tau = (1776.91 \pm 0.12^{+0.10}_{-0.13})\ \mathrm{MeV}/c^2.$$



Data taking @2018

J/ψ scan

#	L, pb^{-1}	W_{cm}, MeV
1	2.50 ± 0.02	3087.659 ± 0.094
2	2.97 ± 0.02	3095.726 ± 0.077
3	5.11 ± 0.02	3096.203 ± 0.069
4	3.07 ± 0.02	3096.986 ± 0.083
5	1.71 ± 0.01	3097.226 ± 0.099
6	4.79 ± 0.02	3097.654 ± 0.082
7	5.75 ± 0.02	3098.728 ± 0.078
8	5.84 ± 0.02	3104.000 ± 0.082
total	31.73 ± 0.06	

τ-threshold scan

1	25.78 ± 0.05	3538.850 ± 0.143
1'	3.99 ± 0.02	3550.828 ± 0.164
2	42.96 ± 0.07	3552.810 ± 0.047
3	27.24 ± 0.06	3553.900 ± 0.072
4	8.34 ± 0.03	3560.285 ± 0.150
5	15.08 ± 0.04	3599.510 ± 0.111
5'	14.87 ± 0.04	3601.385 ± 0.110
total	138.26 ± 0.13	

$\psi(2S)$ scan

#	L, pb^{-1}	W_{cm}, MeV
1	5.09 ± 0.03	3675.440 ± 0.191
2	16.32 ± 0.05	3683.190 ± 0.096
3	3.32 ± 0.02	3684.393 ± 0.201
4	3.66 ± 0.02	3684.193 ± 0.115
5	4.67 ± 0.02	3685.306 ± 0.101
6	6.87 ± 0.03	3685.830 ± 0.095
7	6.20 ± 0.03	3686.302 ± 0.096
8	5.24 ± 0.03	3687.305 ± 0.101
9	5.24 ± 0.03	3687.993 ± 0.096
10	6.13 ± 0.03	3689.773 ± 0.098
11	5.12 ± 0.02	3694.027 ± 0.098
total	67.86 ± 0.09	

Internal review at BESIII

Study of Br(ψ(3686)→$\tau^-\tau^+$)

- $\Psi(2S)$decays to lepton pairs, the relationship of their branching fractions with Lepton Flavor Universality (LFU)

$$\mathrm{B}_{ee} \cong \mathrm{B}_{\mu\mu} \cong \frac{\mathrm{B}_{\tau\tau}}{0.3890} \equiv \mathrm{B}_{ll}$$

- The combined results of B factory and LHCb show a deviation from the SM prediction by 3.1σ. the ratio read

$$R(D^*) = \frac{\Gamma(B\to D^{(*)}\tau^+ \upsilon_\tau)}{\Gamma(B\to D^{(*)}\, l^+ \upsilon_l)} \quad (l = e, \mu)$$

- BESIII Collaboration have collected about 3B $\psi(2S)$ events, more precise measurements are expected

Data and event selection

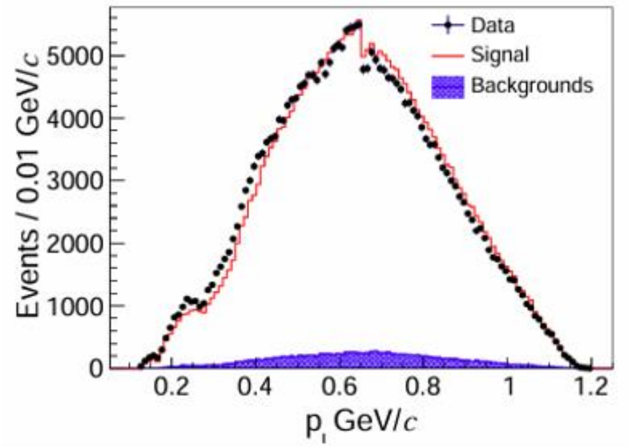
- Data sets : $\psi(2S)$ 2259.3M (2021)
- Signal MC: $\psi(2S) \to \tau^{\pm}\tau^{\mp}\ (e^{\pm}\nu_e\nu_\tau\mu^{\mp}\nu_\mu\nu_\tau)$ (ConExc)

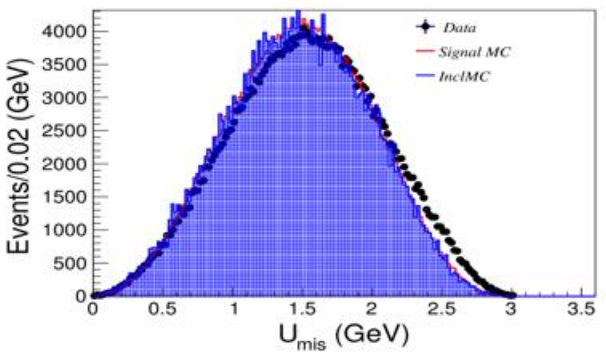
◆**Charged track**
- Vr<1cm, |Vz|<10cm
- |cosθ|<0.93
- Ngood=2

◆**Neutral track**
- Emc>0.025GeV(barrel),Emc>0.050 GeV(Endcap)
- $0<T_{EMC}<14$(x50ns)
- $\theta(\gamma,trk)>10^0$

◆**Final selection**
- E1/p1>0.6 & E2/p2>0.6 veto ee
- E1/p1<0.4 & E2/p2<0.4 veto μμ
- $10^0<\theta(\mu,e)<170^0$
- $\theta(trk,beam)>20^0$

◆**Final selection**
- p1>0.1 & p1<1.2 GeV/c
- P2>0.1 & p2<1.2 GeV/c
- emc1>0.05& emc1<1.15 GeV
- mrecll<3.05 GeV/c^2
- at least one electron & N_π=0 (PID)





Cross section of $\tau^-\tau^+$ at $\psi(3686)$

$$\sigma_{\exp}(s, m_\tau, \Delta) = \int_0^\infty d\sqrt{s'} G(\sqrt{s'}, \sqrt{s}) \times \int_0^{1-\frac{4m_\tau^2}{s'}} dx F(x, s') \frac{\bar{\sigma}_{\text{tot}}(s'(1-x), m_\tau)}{|1-\Pi(s'(1-x))|^2}.$$

Δ Energy spread

s nominal C.M. energy

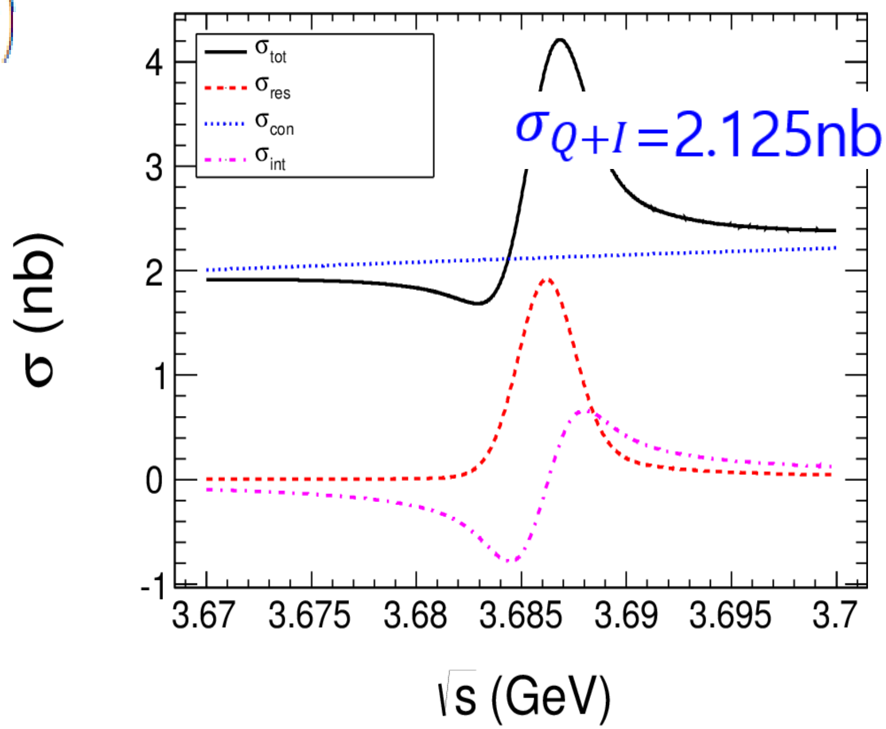
s' actual C.M. energy

$$\bar{\sigma}_{\text{tot}}(s) = F_s(s) \cdot (\sigma_{\text{con}}(s) + \sigma_{\text{int}}(s) + \sigma_{\text{res}}(s)) / \sigma_{\text{con}}(s)$$

$$F_s(s) = \sigma_{\text{con}}(s) \cdot \frac{\pi(3-v^2)}{1-\exp(-\pi\alpha/v)}$$

$$v^2 \equiv 1 - \frac{4m_\tau^2}{s}.$$

$$\sigma_{\text{con}}(s) = \frac{4\pi\alpha^2}{3s},$$
$$\sigma_{\text{res}}(s) = \frac{12\pi\Gamma_e^2}{(s-M_R^2)^2 + M_R^2\Gamma_\tau^2},$$
$$\sigma_{\text{int}}(s) = \frac{8\alpha\Gamma_e}{\pi\sqrt{s}} \frac{s-M_R^2}{(s-M_R^2)^2 + M_R^2\Gamma_\tau^2}$$



BR and Systematic uncertainty

$$B(\tau\tau) = \frac{\frac{N_{e\mu} - N_{bg}}{B\varepsilon} - \sigma_{Q+I}\mathcal{L}}{N_{\psi(2S)}}$$

This term is estimated by QED calculation

Nobs	Nbkg	$\mathcal{L}$ (pb^{-1})	ε	σ(nb)	$N_{\psi'}(10^6)$	$Br(10^{-3})$
280412	11839	3208.5	0.3065	2.125	2259.3	3.240±0.023(sta.) ±0.081(sys.)
This work				$(3.240\pm0.084)\times10^{-3}$		

- tracking efficiency 1%
- $\psi(2S)$ total number 0.5%
- MC statistic $\frac{1}{\sqrt{N}}\frac{\sqrt{(1-\varepsilon)}}{\sqrt{\varepsilon}}$ 0.1%
- Tau branching fraction 0.3%
- Luminosity 1.1%
- PID for e & μ 1.2%
- μ and π separation 0.5%
- N_γ requirement 1.0%
- M_{mis} requirement 0.8%
- $|\cos\theta_{mis}|$ requirement 0.1%
- Background rejection 0.3%
- cross section calculation 0.4%
- Total systematic uncertainty 2.5%

$(3.1 \pm 0.4) \times 10^{-3}$ (PDG)

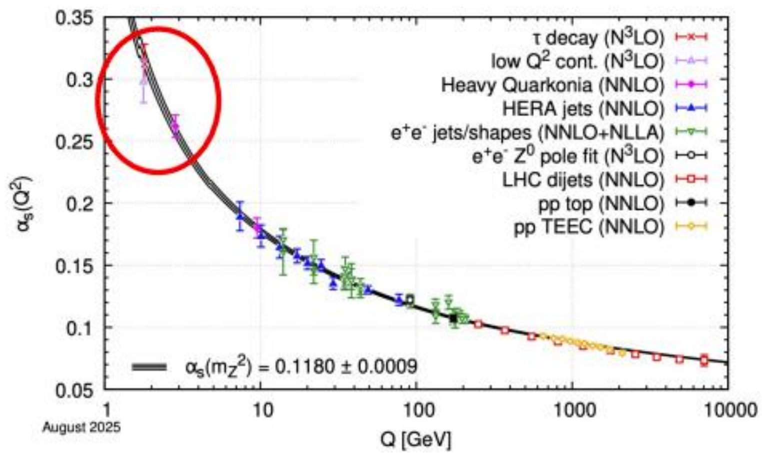
- The branching fraction $\mathcal{B}_{\tau\tau}$ of $\psi(2S) \rightarrow \tau^+\tau^-$ has been measured with improved precision.
- Assuming lepton universality, the average value of branching fraction of lepton pairs $\mathcal{B}_{ll}$ are determined and total width of resonance $\psi(2S)$ has been calculated.
- This result, along with previous data of $\mathcal{B}_{ee}$ and $\mathcal{B}_{\mu\mu}$ is in agreement with the relation predicted by the sequential lepton hypothesis.

B_{ee} (10^{-3})	$B_{\mu\mu}$(10^{-3})	$B_{\tau\tau}$ /0.3890 (10^{-3})
7.93±0.17	8.00±0.60	8.33±0.24

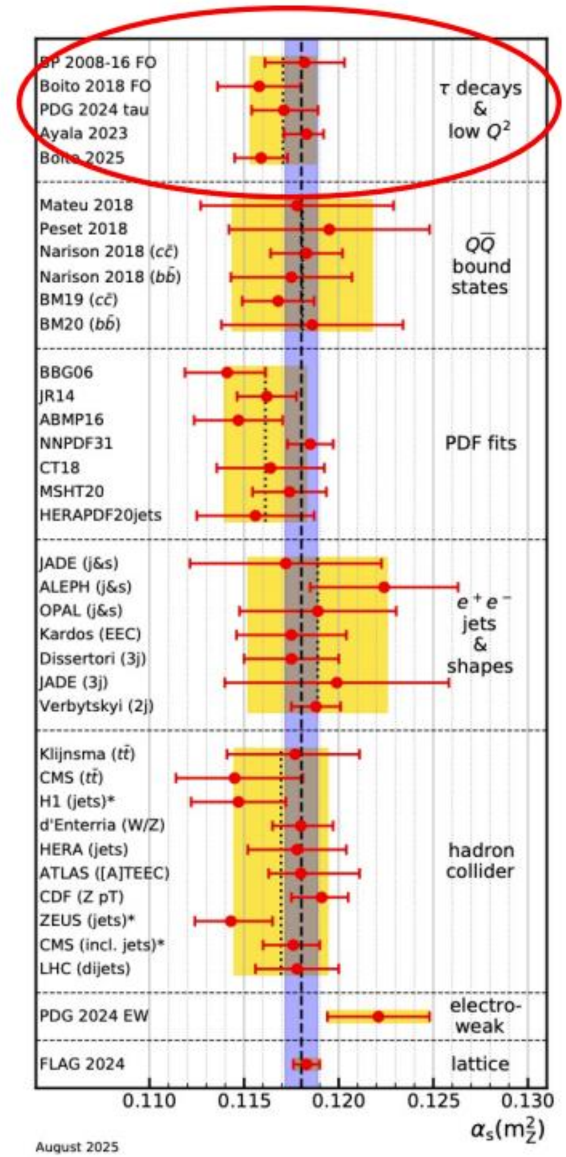
Measurement of α_s

The strong coupling constant α_s :

- A fundamental parameter of the Standard Model (SM) of particle physics and Quantum Chromodynamics (QCD).
- The least understood among the three coupling constants.



- Be determined from R value, /Z/W decays, jet production, event shapes, and other processes.
- Hadronic τ decays provide one of the most precise low-energy determination



Measurement of α_s

CLEO: Phys. Lett. B.356, 580 (1995)

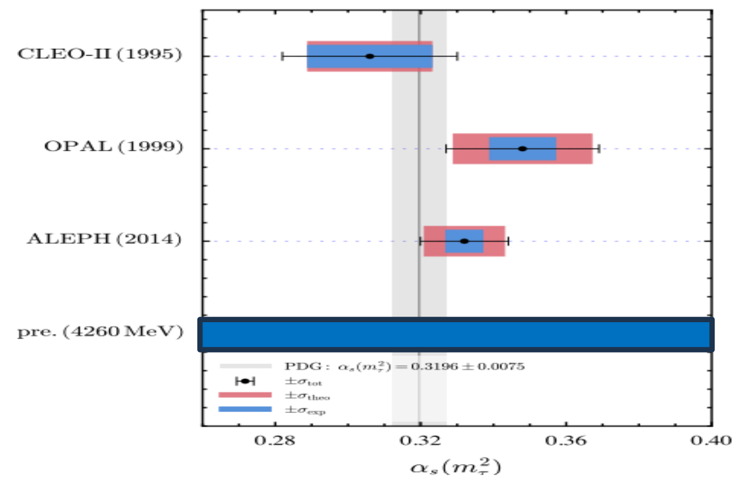
- 3 fb^{-1} data @ ~10 GeV → N_{sig} = ~175906
- Double tag method: Used $\tau^+ \to e^+\bar{\nu}_\tau\nu_e$ and $\tau^+ \to \mu^+\bar{\nu}_\tau\nu_e$ tag mode.
- Perturbative treatment: CIPT-type calculation
- Result: $\alpha_s(m_\tau^2) = 0.306 \pm 0.024$
- Evolved to the Z−boson scale: $\alpha_s(M_Z^2) = 0.114 \pm 0.003$

ALEPH: Eur. Phys. J. C 74, 2803 (2014)

- Full LEP-1 data sample collected at the Z pole
- 12435 τ decays
- Perturbative treatment:
  Both CIPT and FOPT were used; their average was taken as the nominal result, with half of their difference included in the theoretical uncertainty.
- Result: $\alpha_s(m_\tau^2)$ = 0.332 ± 0.005 ± 0.011
- Evolved to Z−boson: $\alpha_s(m_Z^2)$ = 0.1199 ± 0.0015

OPAL: Eur. Phys. J. C 7, 571 (1999)

- Full LEP-1 data sample collected at the Z pole
- 297988 τ decays
- Perturbative treatment:
  CIPT was used for the nominal result. FOPT and renormalon-chain resummation were also compared.
- Result: $\alpha_s(m_\tau^2)$ = 0.348 ± 0.009 ± 0.019
- Z−boson: $\alpha_s(m_Z^2)$ = 0.1219 ± 0.0010 ± 0.001



Measurement of α_s

BESIII

- 826.7 pb^{-1} data @ 4.26 GeV
- 6.8 $\times 10^4$ selected events
- Double tag method:

  Tag: $\tau^+ \rightarrow e^+ \nu_e \bar{\nu}_\tau$

  $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$, $\tau^- \rightarrow \pi^- 2\pi^0 \nu_\tau$,

  $\tau^- \rightarrow \pi^- 3\pi^0 \nu_\tau$, $\tau^- \rightarrow 2\pi^- \pi^+ \nu_\tau$,

  $\tau^- \rightarrow 2\pi^- \pi^+ \pi^0 \nu_\tau$, $\tau^- \rightarrow 2\pi^- \pi^+ 2\pi^0 \nu_\tau$,
- CIPT was used nominally, with FOPT included in the theory uncertainty

BESIII

Memo version 6

BESIII Analysis Memo

BAM-1105

June 4, 2026

Measurement of the Strong Coupling Constant $\alpha_s(m_\tau^2)$ from hadronic τ decay

Yuzhi Che[a,c], Yaquan Fang[a,b], Yanping Huang[a], Gang Li[a], Xinchou Lou[a,b], Zhaoru Zhang[a], Manqi Ruan[a], Ligang Shao[a,b], Jinfei Wu[a,c], Gengyuan Zhang[a,b], and Huaqiao Zhang[a]

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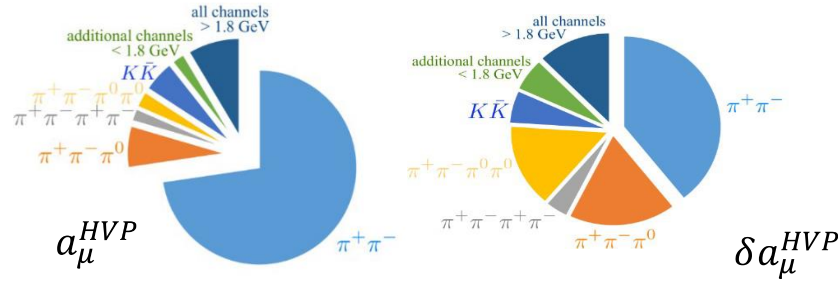
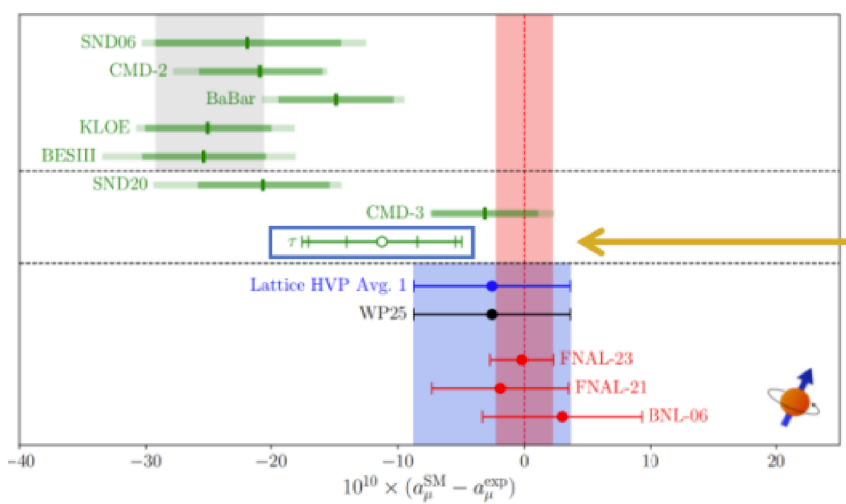
Internal review at BESIII

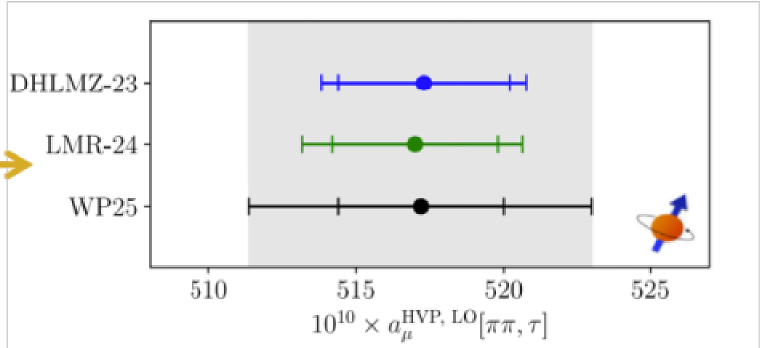
Study of $\tau^- \to \pi^- \pi^0 \nu_\tau$

The anomalous magnetic moment $a_\mu = \frac{g_\mu - 2}{2}$

The Most Precise Physical Quantity







There is a discrepancy between the experimental and theoretical values of a_μ, as derived from a comparison of the $e^+e^- \to \pi^+\pi^-$ cross-section measurement and the $\tau^- \to \pi^- \pi^0 \nu_\tau$ mass sprectum

Study of $\tau^- \to \pi^- \pi^0 \nu_\tau$ helps to provide experimental inputs required for the theoretical calculation of a_μ.

Study of $\tau^- \to \pi^- \pi^0 \nu_\tau$

CLEO: Phys. Rev. Lett. 72, 3762 (1994)

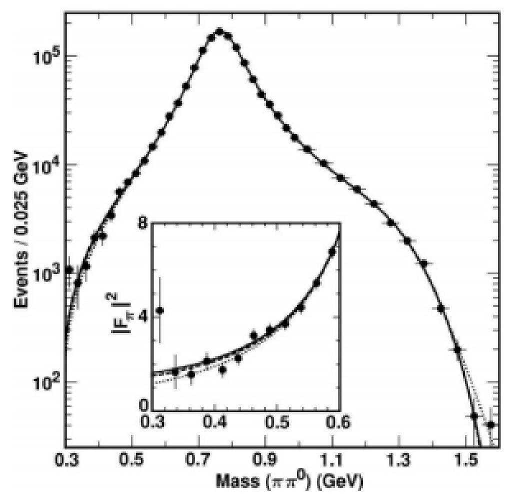
- 1.58 fb^{-1} data @ 10.6 GeV
- 44K events observed
- Method: $\tau^- \to \pi^- \pi^0 \nu_\tau$ is reconstructed with e , μ , ρ or three-prong tags
- After subtracting $\tau^- \to K^- \pi^0 \nu_\tau$,

  $\mathcal{B}(\tau^- \to \pi^- \pi^0 \nu_\tau) = (25.36 \pm 0.44)\%$

CLEO: Phys. Rev. D 61, 112002 (2000)

- 3.5 fb^{-1} data @ 10.6 GeV
- 95K events observed
- Dominated by ρ(770) and a significant ρ'(1450)
- Method: $\tau^- \to \pi^- \pi^0 \nu_\tau$ is reconstructed with e , μ and ρ tags

Fit Parameter	Model				
	KS	KS w/ρ''	KS w/barrier	GS	GS w/ρ''
M_ρ (MeV)	774.9 ± 0.5	774.6 ± 0.6	769.7 ± 0.7	775.3 ± 0.5	775.1 ± 0.6
Γ_ρ (MeV)	149.0 ± 1.1	149.0 ± 1.2	145.8 ± 1.3	150.5 ± 1.1	150.4 ± 1.2
β	-0.108 ± 0.007	-0.167 ± 0.008	-0.160 ± 0.008	-0.084 ± 0.006	-0.121 ± 0.009
$M_{\rho'}$ (MeV)	1364 ± 7	1408 ± 12	1321 ± 9	1365 ± 7	1406 ± 13
$\Gamma_{\rho'}$ (MeV)	400 ± 26	502 ± 32	397 ± 17	356 ± 26	455 ± 34
R_ρ (GeV^{-1})	—	—	1.9 ± 0.3	—	—
$R_{\rho'}$ (GeV^{-1})	—	—	5.0 ± 2.2	—	—
γ	$\equiv0$	0.050 ± 0.010	$\equiv0$	$\equiv0$	0.032 ± 0.009
$\lvert F_\pi(0)\rvert^2$	1.16 ± 0.02	1.14 ± 0.02	0.39 ± 0.01	1.04 ± 0.02	1.03 ± 0.02
χ^2/DOF	27.0/24	23.2/23	22.9/22	26.8/24	22.9/23



Study of $\tau^- \to \pi^- \pi^0 \nu_\tau$

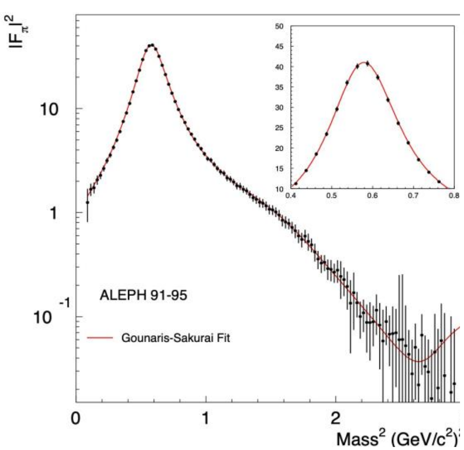
ALEPH: Phys. Rept. 421:191-284 (2005)

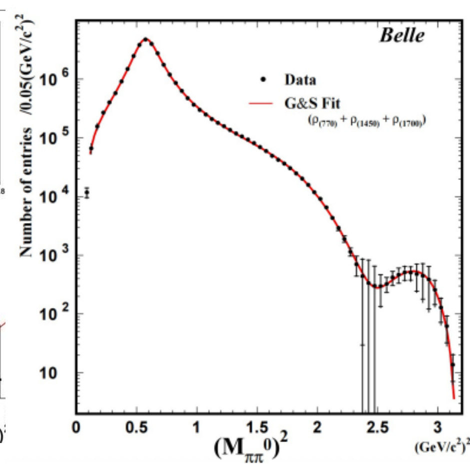
- Full LEP-1 data sample collected at the Z pole
- 81K events observed
- $\mathcal{B}(\tau^- \to \pi^- \pi^0 \nu_\tau)$ = (25.471 $\pm$ 0.097 $\pm$ 0.085)%
- ALEPH classified each τ decay according to its charged track and π^0 multiplicities ; Branching fractions are obtain globally
- The unfolded $\pi^- \pi^0$ spectral function is dominated by the ρ(770) and ρ'(1450) with weak ρ''(1700)

Belle: Phys. Rev. D 78, 072006 (2008)

- 72.2 fb-1 data @ 10.58 GeV
- 5.4M events observed
- $\mathcal{B}(\tau^- \to \pi^- \pi^0 \nu_\tau)$ = (25.24 $\pm$ 0.01 $\pm$ 0.39)%
Spectrum: the unfolded mass spectrum is described by the ρ(770), ρ'(1450) and ρ''(1700) contributions with the one charged track from tag side

Parameter	ALEPH GS
$m_{\rho^\pm(770)}$ (MeV)	775.5 ± 0.7
$\Gamma_{\rho^\pm(770)}$ (MeV)	149.0 ± 1.2
β	0.120 ± 0.008
ϕ_β (degrees)	153 ± 7
$m_{\rho^\pm(1450)}$ (MeV)	1328 ± 15
$\Gamma_{\rho(1450)}$ (MeV)	468 ± 41
γ	0.023 ± 0.008
$m_{\rho^\pm(1700)}$ (MeV)	[1713]
$\Gamma_{\rho(1700)}$ (MeV)	[235]
χ^2/DF	119/110





Parameter	Fit result (fixed $\lvert F(0)\rvert^2$)	Fit result (all free)
M_ρ, MeV/c^2	$774.6 \pm 0.2 \pm 0.5$	$774.9 \pm 0.3 \pm 0.5$
Γ_ρ, MeV	$148.1 \pm 0.4 \pm 1.7$	$148.6 \pm 0.5 \pm 1.7$
$M_{\rho'}$, MeV/c^2	$1446 \pm 7 \pm 28$	$1428 \pm 15 \pm 26$
$\Gamma_{\rho'}$, MeV	$434 \pm 16 \pm 60$	$413 \pm 12 \pm 57$
$\lvert\beta\rvert$	$0.15 \pm 0.05^{+0.15}_{-0.04}$	$0.13 \pm 0.01^{+0.16}_{-0.04}$
ϕ_β, degree	$202 \pm 4^{+41}_{-8}$	$197 \pm 9^{+50}_{-5}$
$M_{\rho''}$, MeV/c^2	$1728 \pm 17 \pm 89$	$1694 \pm 41 \pm 89$
$\Gamma_{\rho''}$, MeV	$164 \pm 21^{+89}_{-26}$	$135 \pm 36^{+50}_{-26}$
$\lvert\gamma\rvert$	$0.037 \pm 0.006^{+0.065}_{-0.009}$	$0.028 \pm 0.020^{+0.059}_{-0.009}$
ϕ_γ, degree	$24 \pm 9^{+118}_{-28}$	$-3 \pm 13^{+136}_{-29}$
$\lvert F(0)\rvert^2$	[1.0]	$1.02 \pm 0.01 \pm 0.04$
χ^2/NDF	80/52	65/51
$\rho''(1700)$ signif., σ	6.5	7.0

Study of $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$

BESIII

- 20.3 fb-1 data @ 3.773 GeV
- 1.2M events observed
- Branching fraction and unfolded mass spectrum

- The relative uncertainty of statistic error will be less then 0.2%, statistic error will be less then 1.0%.

Memo version 1.3

BESIII Analysis Memo

BAM-xxx

June 26, 2026

The Study of $\tau^- \to \pi^- \pi^0 \nu_\tau$

Shan-Shan Li [1] [a], Heng Ma[a], Shu-Lei Zhang [2a], Jian-Yong Zhang[b], Jie-Sheng Yu[a], Ling-Yun Dai[a], and Xi-Qing Hao[c]

[a]*Hunan University*
[b]*Institute of High Energy Physics, CAS*
[c]*Henan Normal University*

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[e]*Uni E*
[f]*Uni F*

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[g]*Uni. G*
[h]*Uni. H*

Internal review at BESIII

Study of $\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$

CLEO: Phys. Rev. Lett. 90, 181802 (2003)

- 3.26 fb^{-1} data @ 10.6 GeV
- 43K events observed
- $Br(\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau) = (9.13 \pm 0.05 \pm 0.46)$ %

ALEPH: Phys. Rept. 421:191-284 (2005)

- Full LEP-1 data sample collected at the Z pole
- 29K events observed
- $Br(\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau) = (9.041 \pm 0.060 \pm 0.076)$ %

BABAR: Phys. Rev. Lett.100, 011801 (2008)

- 342 fb^{-1} data @ 10.58 GeV
- 1.6M events observed
- $Br(\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau) = (8.830 \pm 0.01 \pm 0.13)$ %

Belle: Phys. Rev. D 81, 113007 (2010

- 666 fb^{-1} data @ 10.58 GeV
- 8.9M events observed
- $Br(\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau) = (8.420 \pm 0.00 {}^{+0.25}_{-0.26})$%

BESIII

- 2.7B $\psi(2S)$ data are used
- Double tag method:
  Tag: $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$
  $\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau$
- 22K events observed
- Br consistent with PDG
- a1 parameters determined precisely

Internal review at BESIII

Study of $\tau^- \to K^- \pi^0 \nu_\tau$

$|V_{US}|$

- $|V_{US}|$ provides a stringent test of first-row CKM unitarity.
- Current determinations show some tensions with CKM unitarity:
  - Kaon decays: 2.3σ lower than the CKM-unitarity prediction.
  - τ decays: 3.7σ/2.0σ lower for the inclusive/exclusive determination
- Precise measurements of strange decays provide an independent determination of $|V_{US}|$ and help clarify the discrepancy

$$|V_{\rm CKM}| = \begin{pmatrix} 0.97367 \pm 0.00032 & \boxed{0.22431 \pm 0.00085} & 0.00389 \pm 0.00016 \\ 0.2261 \pm 0.0027 & 0.9669 \pm 0.0038 & 0.0407 \pm 0.0013 \\ 0.0086 \pm 0.0002 & 0.0415 \pm 0.0009 & 1.002 \pm 0.024 \end{pmatrix}$$

Study of $\tau^- \to K^- \pi^0 \nu_\tau$

CLEO: Phys. Rev. Lett. 73, 1079 (1994)

- 1.58 fb^{-1} data @ 10.6 GeV
- 35.3 events observed
- $\mathcal{B}(\tau^- \to K^- \pi^0 \nu_\tau) = (0.51 \pm 0.10 \pm 0.07)\%$

BABAR: Phys. Rev. D 76, 051104 (2007)

- 230.2 fb^{-1} data @ 10.58 GeV
- 78K events observed
- $\mathcal{B}(\tau^- \to K^- \pi^0 \nu_\tau) = (0.416 \pm 0.003 \pm 0.018)\%$

OPAL: Eur. Phys. J. C 35, 437 (2004)

$\mathcal{B}(\tau^- \to K^- \pi^0 \nu_\tau) = (0.471 \pm 0.064 \pm 0.022)\%$

BESIII

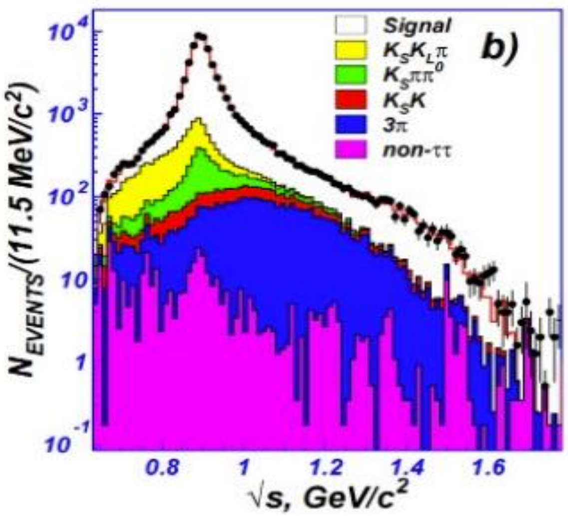
- 20.3 fb^{-1} data @ 3.773 GeV
- 16K events observed

Still in progress

Study of $\tau^- \to K^0 \pi^- \nu_\tau$

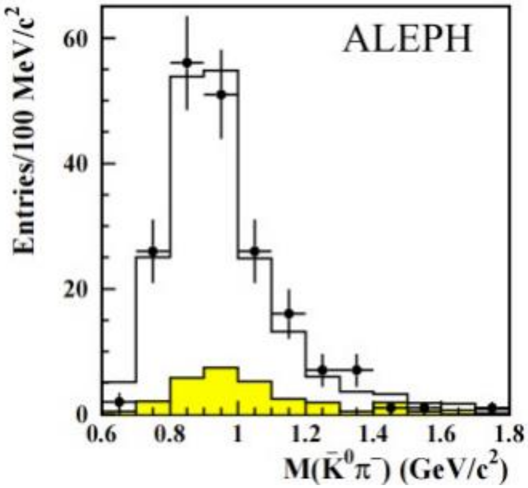
Belle: Phys. Lett. B 654, 65 (2007)
Phys. Rev. D 89, 072009 (2014)

- 699 fb^{-1} data @ 10.58 GeV
- 1578K events
- $\mathcal{B}(\tau^- \to K^0 \pi^- \nu_\tau) = (0.8320 \pm 0.0025 \pm 0.0150)\%$
- The K_S^0 reconstructed through $K_S^0 \to \pi^+\pi^-$, the opposite τ was identified with a leptonic tag.
- The $K_S^0 \pi^-$ mass spectrum is described $K^*(892)$, ($K_0^*(800)$ and $K^*(1410)$.



ALEPH: Eur. Phys. J. C 11, 599 (1999)

- $\mathcal{B}(\tau^- \to K^0 \pi^- \nu_\tau) = (0.928 \pm 0.045 \pm 0.034)\ \%$



OPAL: Eur. Phys. J. C 13, 213 (2000)

- $\mathcal{B}(\tau^- \to K^0 \pi^- \nu_\tau) = (0.933 \pm 0.068 \pm 0.049)\%$

Study of $\tau^- \to K^0 \pi^- \nu_\tau$

Search for CPV in $\tau^- \to \pi^- K_S^0(\to \pi^+\pi^-)\nu_\tau(\geq 0\pi^0)$

$$A_{(CP)}^{SM} = \frac{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S^0 \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S^0 \nu_\tau)}$$

- SM predicts $A_{(CP)}^{SM} \simeq (0.33 \pm 0.01)\%$
- any significant deviation from the SM expectation could indicate the new physics.

BABAR: Phys. Rev. D 85, 031102 (2012)

- 476 fb^{-1} data @ 10.58/10.54 GeV
- BABAR reconstructed $\tau^- \to K^0 \pi^- \nu_\tau$ using lepton tagged samples
- A_{CP} = (−0.36 $\pm$ 0.23 $\pm$ 0.11) % (2.8σ deviation from SM)

BESIII

- 20.3 fb^{-1} data @ 3.773 GeV
- 16K events observed

Still in progress

Belle II: M. Mantovano, FPCP 2026

- 361.65 fb^{-1} data
- two-steps BDT to suppress qqbar and tau backgrounds → >98% of signal purity
- $\tau^- \to K_S^0 \pi^- \nu_\tau(\geq 0\pi^0)$, τ^+(tag)$\to l\, \nu_l \bar{\nu}_\tau$
- A_{CP} = (0.71 $\pm$ 0.26 $\pm$ 0.06 $\pm$ 0.15) % (consistent with SM within 1.24σ)

Summary

- BESIII provides an independent study of decays in a low-energy e^+e^- environment.
- More analysises are in progress.
- Data in both the high-energy (4.9-5.6GeV) and low-energy (1.0-2.0GeV) regions will facilitate further research after upgrade of BEPCII.