Tau physics at BESIII

Zhang Jianyong

on behalf of Tau physics group

Symposium on 30 years of

BES physics

Participants

- Budker institute of nuclear physics, Russia

E.V. Abakumova, M.N. Achasov, V.E. Blinov, V.V. Kaminsky, A.A. Krasnov, N.Yu. Muchnoi, I.B. Nikolaev,, E.E. Pyata, A.G. Shamov, K.Yu. Todyshev, G.S. Varner, A.A. Zhukov ……

- University of Hawaii, USA

F.A. Harris, S.L. Olsen, Q. Liu, C.P. Shen, T. Luo, M. Kornicer……

- Tsinghua university, China

Y.N. Gao, L.G. Xia, F.F. Jing ……

- Wuhan university

Y. K. Wang ……

- Zhengzhou university

C. F. Hua, W. B. Song ……

- Institute of high energy physics, China

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Outline

- Introduction
- BEPCII and BESIII
- Tau lepton mass measurement
- Test to standard model and beyond
- Summary

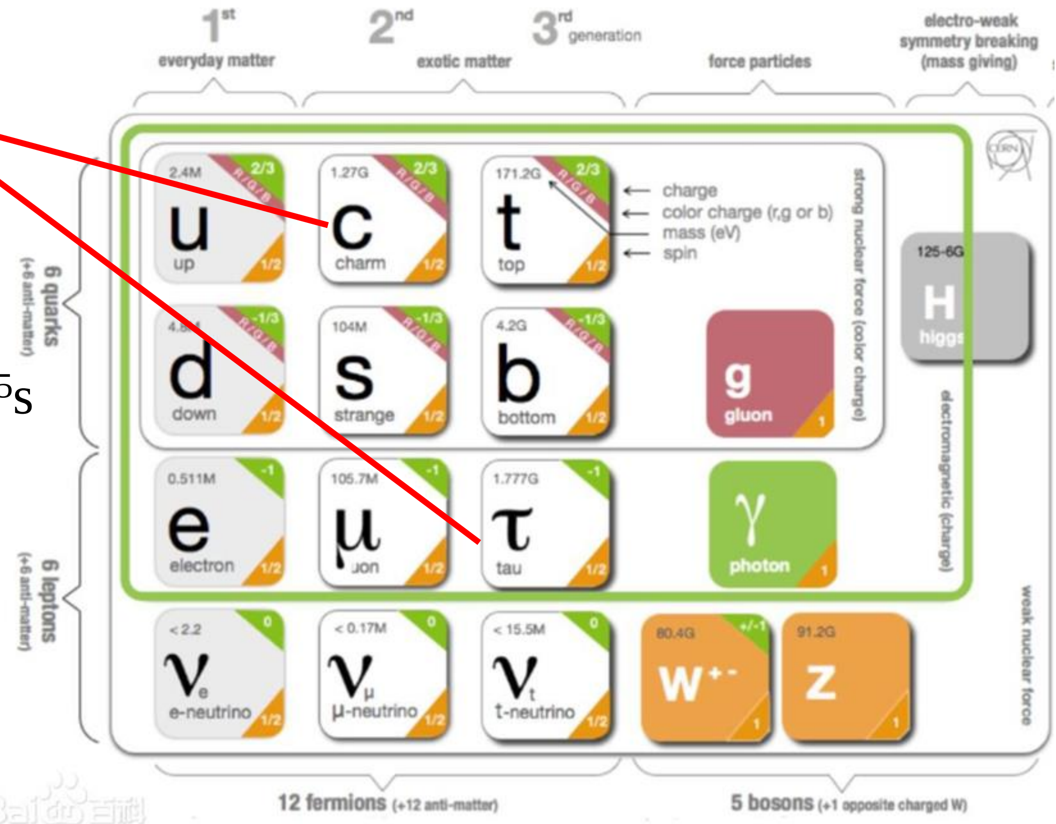
Introduction

BEPCII, BESIII

Found by MARKI in 1975

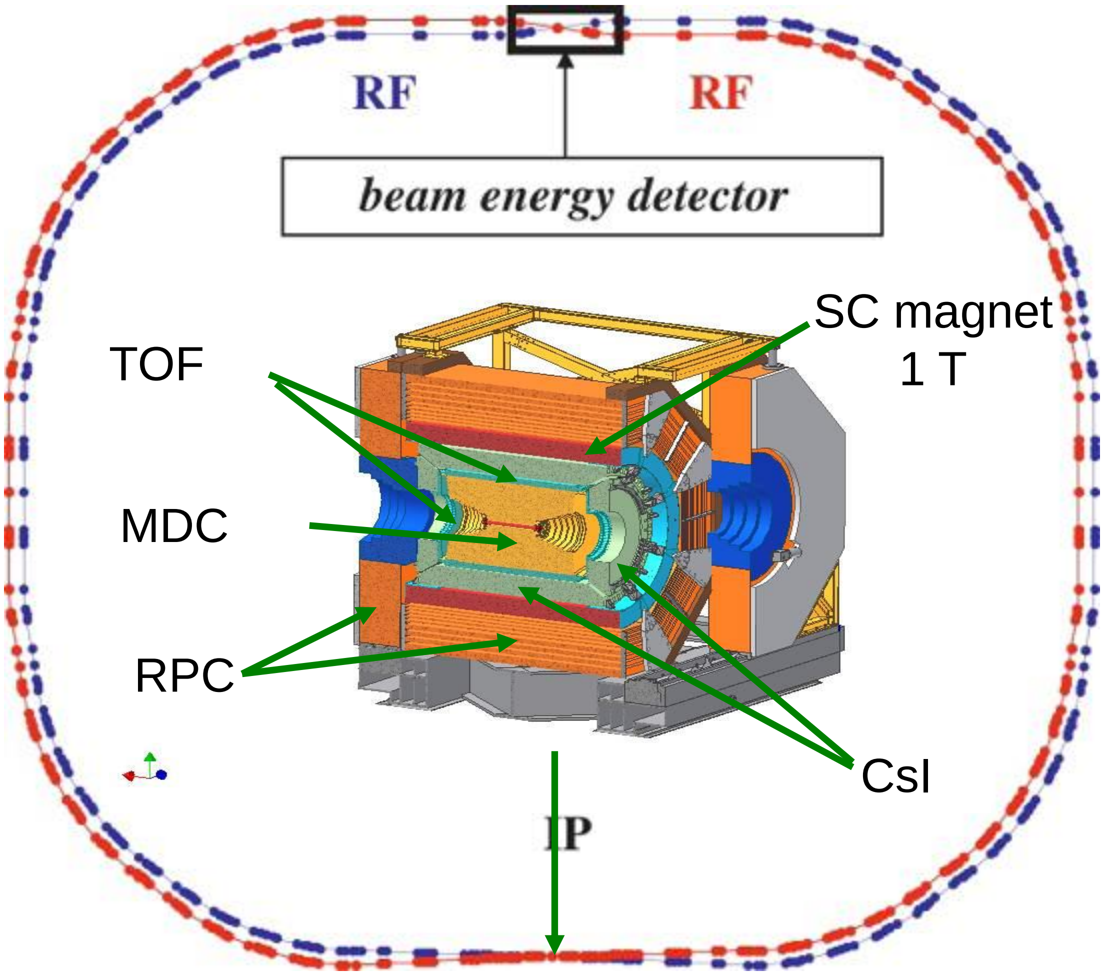
Mean life: $(290.3 \pm 0.5) \times 10^{-15}$s

$m_\tau = 1776.86 \pm 0.12$ MeV



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

BEPCII and BESIII



BEPCII

Energy region: 2.0 ~ 4.6GeV
Luminosity: 10^{33} cm^{-2}s^{-1} @1.89GeV
bunch: 2×93
current: 2×0.91A

BESIII

DC： position： 135 μm，
momentum： 0.5%@1GeV,
$\sigma_{dE/dx}$： 6%

EMC： 2.5%@1GeV
6 (9) mm

TOF： 65 ps (B)
60 ps（EC）

μ counter : 9 layers (B)
8 layers（EC）

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}) ;
  $m_\tau = 1776.86 \pm 0.12$ MeV (6.8×10^{-5})

- Leptonic universality test

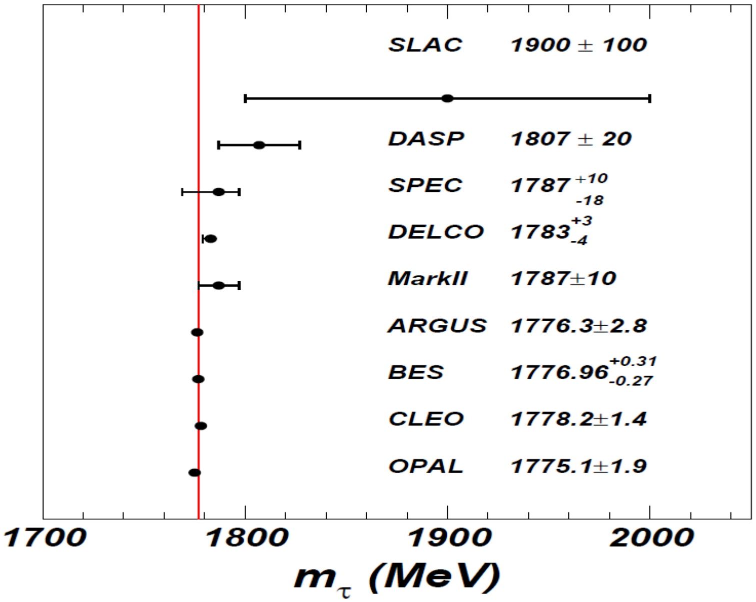
$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\tau_\mu}{\tau_\tau}\left(\frac{m_\mu}{m_\tau}\right)^5 \frac{B(\tau \to e\nu_e\nu_\tau)}{B(\mu \to e\nu_e\nu_\mu)}(1+\Delta_e)$$

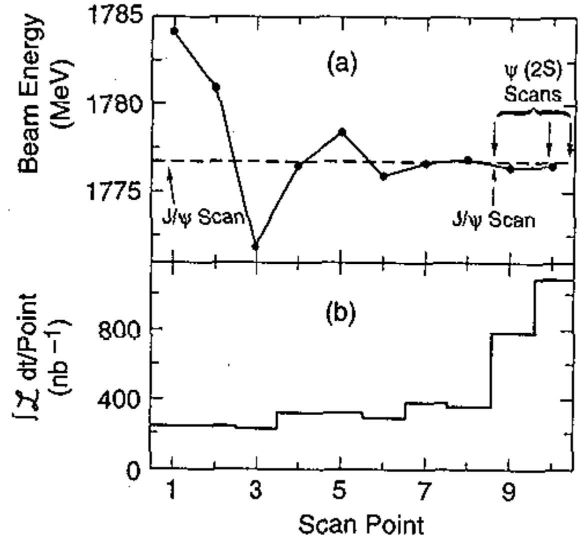
τ mass is sensitive to universality: m_τ^5

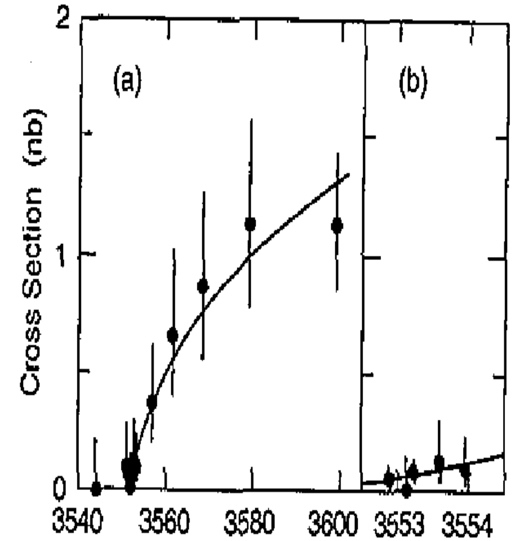
- Threshold scan method is used

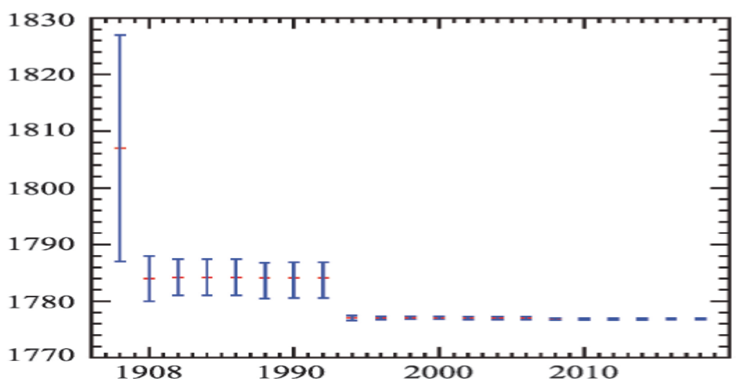
History of M_τ measurement

see Walter Toki's talk







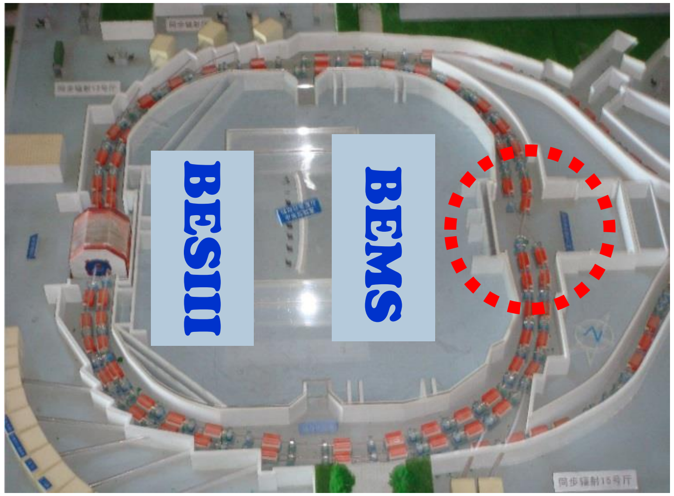


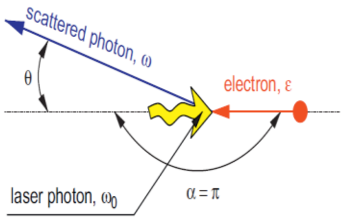
Measurement results of m_τ in the 21 century.

Measured m_τ (value+statistic+systematic)	Year	Exp. Group	Data sample	Method
$1776.91 \pm 0.12^{+0.10}_{-0.13}$	2014	BESIII	$23.26\ pb^{-1}$	Threshold-scan
$1776.68 \pm 0.12 \pm 0.41$	2009	Babar	$423\ fb^{-1}$	Pseudo-mass
$1776.81^{+0.25}_{-0.23} \pm 0.15$	2007	KEDR	$6.7\ pb^{-1}$	Threshold-scan
$1776.61 \pm 0.13 \pm 0.35$	2007	Belle	$414\ fb^{-1}$	Pseudo-mass

Beam energy measurement system (BEMS)

see Alexey's talk



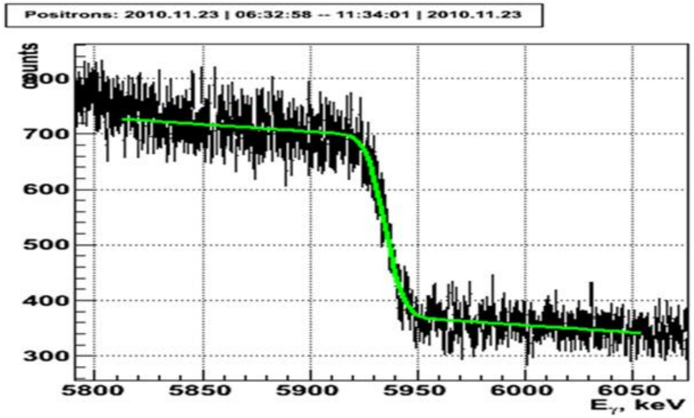


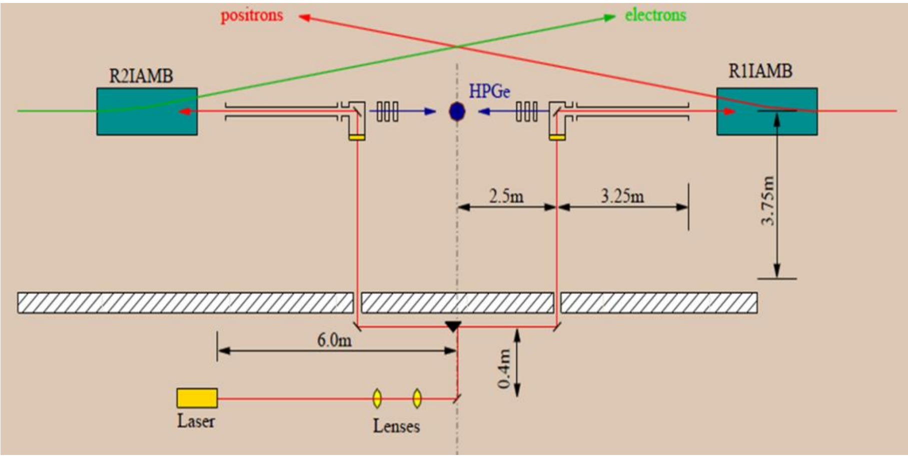
Head on collision, ackscattered photons :

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

Beam energy:

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





Statistical optimization of M_τ

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

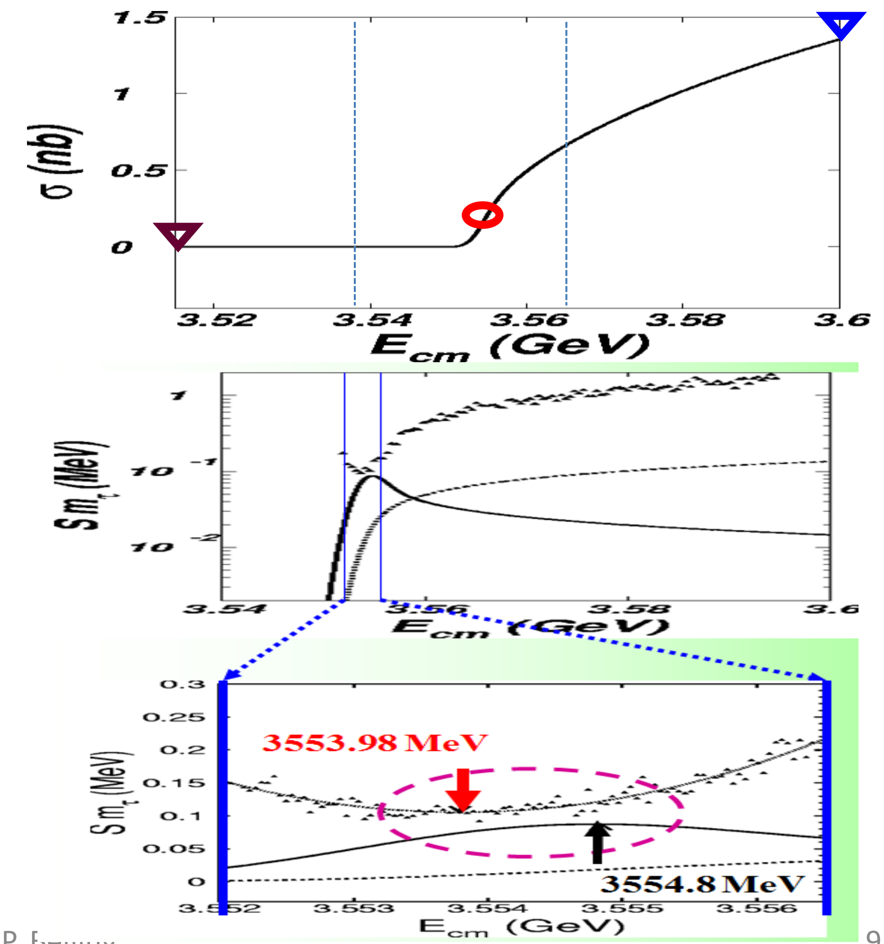
Assume： M_τ is known

To find：

1. What's the optimal distribution of data taking point;
2. How many points are needed in scan experiment;
3. How much luminosity is required for certain precision.

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

$\Delta E_i = E_i - M_\tau$

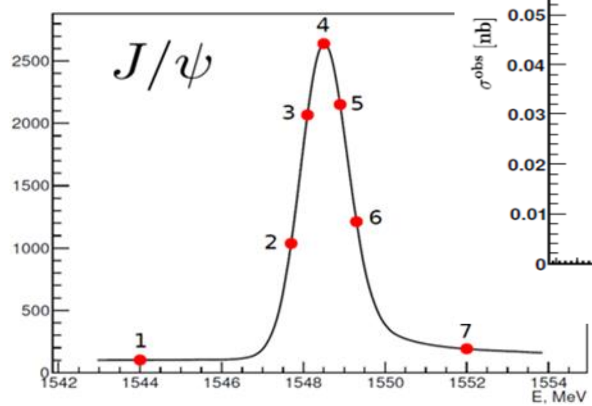


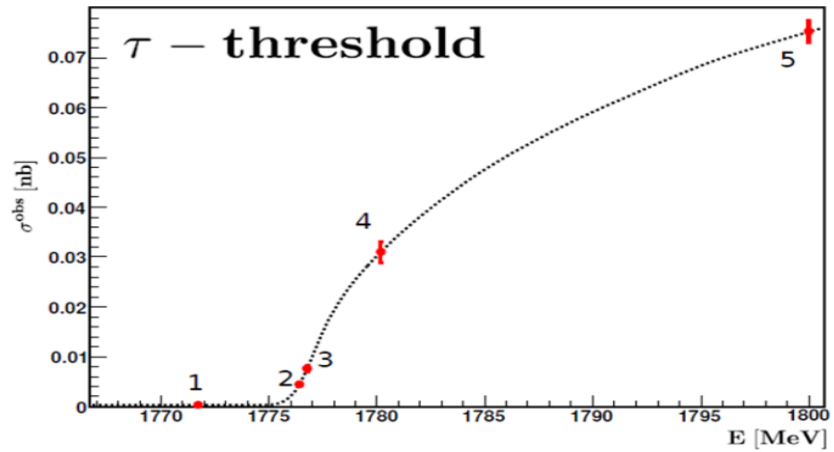
Data taking scenario

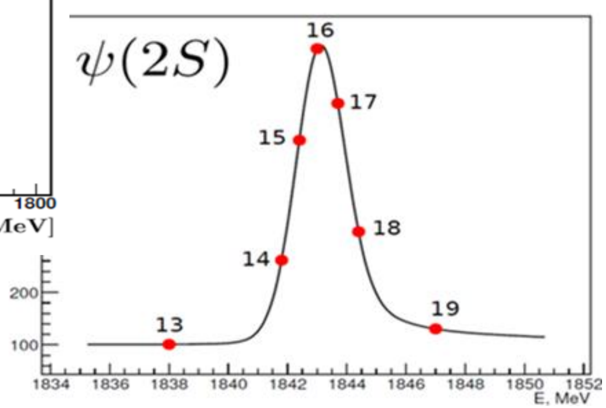
Three stages:

- 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
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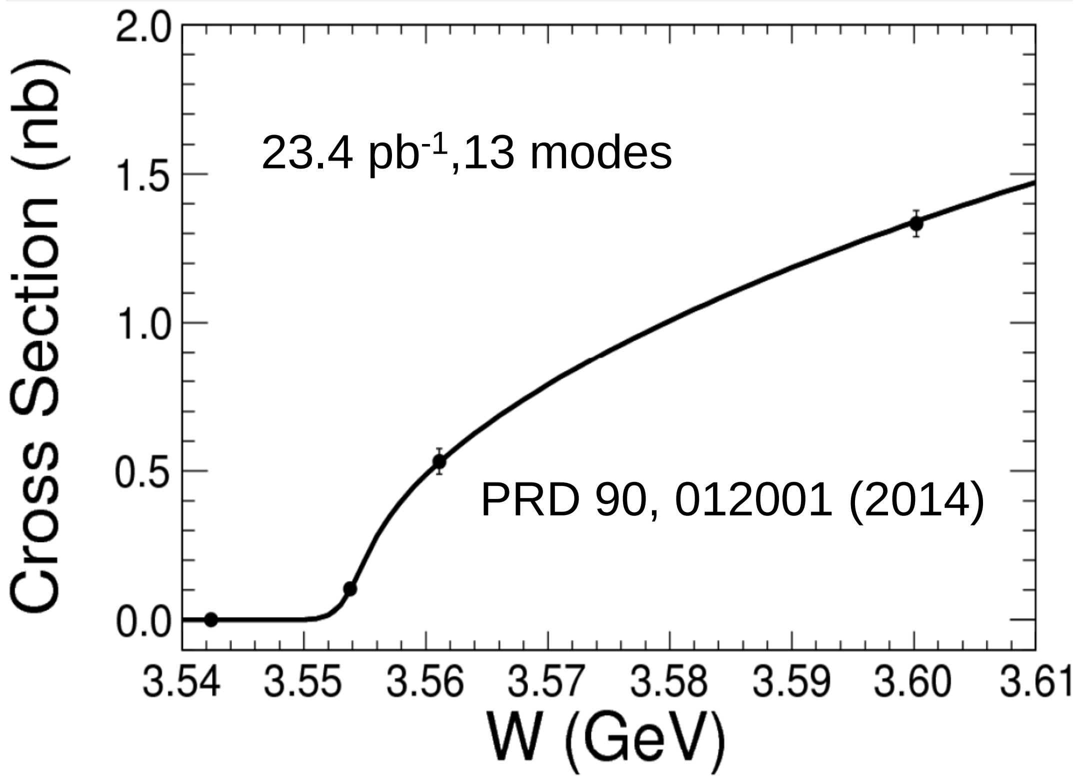
L_i%	14	39	26	7	14

$\Delta E_i = E_i - M_\tau$

Tau scan in 2011

Scan	E_{CM} (MeV)	$\mathcal{L}(nb^{-1})$
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



$M_\tau = 1776.91 \pm 0.12 ^{+0.10}_{-0.13}$ MeV

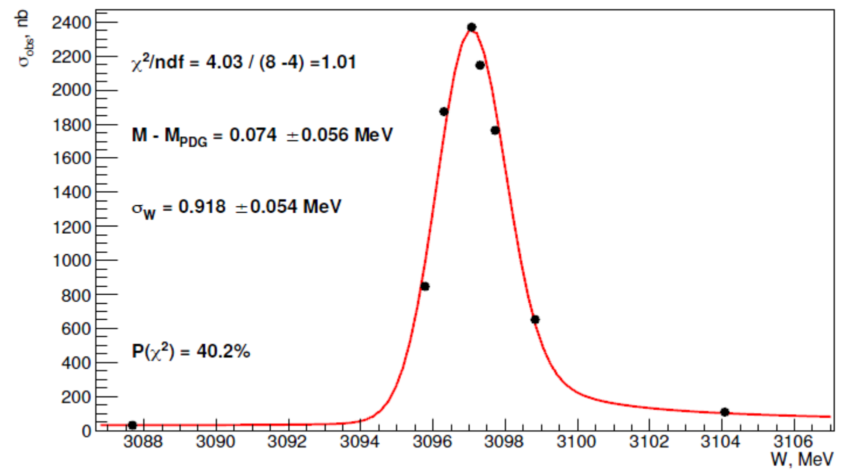
PDG2012: 1776.82 $\pm$0.16 MeV

Tau scan in 2011(II)

final state	1		2		3		4		total	
	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	18	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

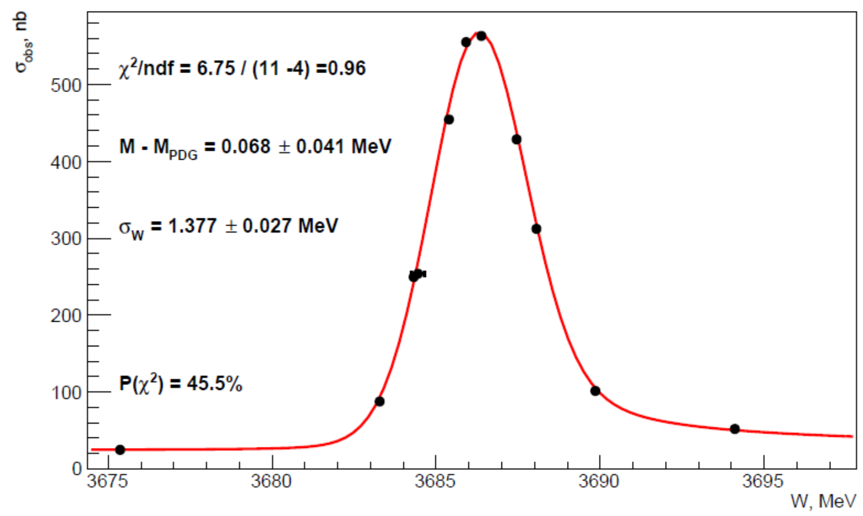
Tau scan in 2018

#	L, pb^{-1}	W_{cm}, MeV
1	2.5	3087.67 ± 0.078
2	3.0	3095.78 ± 0.082
3	6.1	3096.30 ± 0.075
4	3.0	3097.07 ± 0.087
5	1.9	3097.30 ± 0.103
6	4.8	3097.72 ± 0.086
7	5.6	3098.83 ± 0.083
8	5.7	3104.07 ± 0.087
total	32.6	



$\psi(2S)$ scan

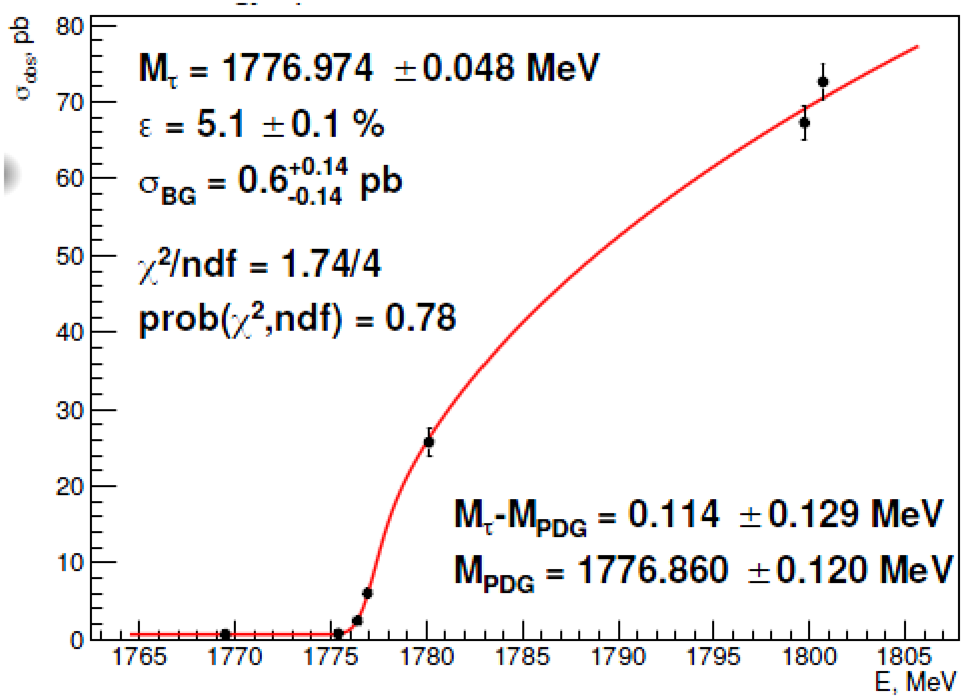
#	L, pb^{-1}	W_{cm}, MeV
1	5.2	3675.37 ± 0.13
2	16.4	3683.28 ± 0.10
3	3.4	3684.45 ± 0.21
4	3.6	3684.32 ± 0.12
5	4.6	3685.39 ± 0.10
6	6.7	3685.92 ± 0.10
7	6.1	3686.38 ± 0.10
8	5.1	3687.45 ± 0.10
9	5.1	3688.06 ± 0.10
10	6.0	3689.85 ± 0.10
11	5.0	3694.11 ± 0.10
total	67.2	



Tau mass scan in 2018 (II)

τ-threshold scan

1	23.8	3539.07 ± 0.05
1'	4.0	3550.87 ± 0.18
2	42.6	3552.87 ± 0.07
3	27.1	3553.93 ± 0.08
4	9.2	3560.36 ± 0.16
5	15.0	3599.57 ± 0.12
5'	14.9	3601.51 ± 0.12
total	136.6	

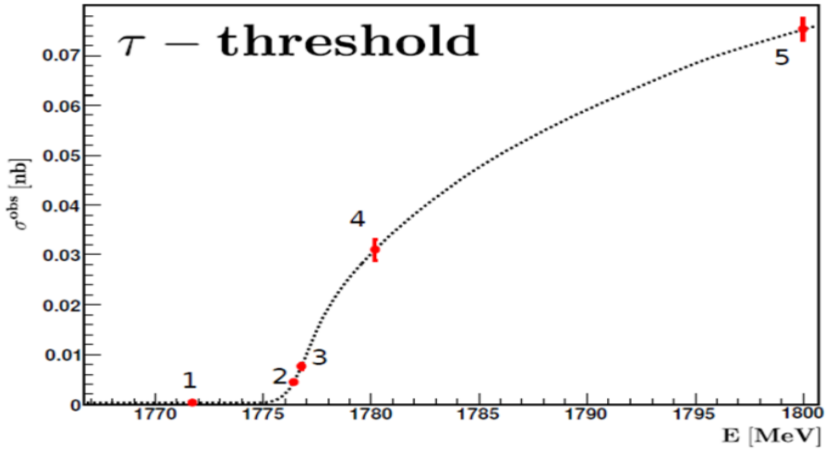


- The systematic uncertainty is in progress
- Uncertainty of M_τ will be less than 0.1MeV

Data comparison between 2011 scan and 2018 scan

Sample	P1	P2	P3	P4	P5	total
2011 scan	$4.3pb^{-1}$		$5.6pb^{-1}$	$3.9pb^{-1}$	$9.6pb^{-1}$	$23.4pb^{-1}$
2018 scan	$27.8pb^{-1}$	$42.6pb^{-1}$	$27.1pb^{-1}$	$35.6pb^{-1}$	$29.9pb^{-1}$	$136.6pb^{-1}$

Sample	J/ψ	ψ'
2011 scan	$1.5pb^{-1}$	$7.5pb^{-1}$
2018 scan	$38pb^{-1}$	$68pb^{-1}$



Test of standard model

$$\Gamma(D^+ \to \ell^+ \nu_\ell) = \frac{G_F^2}{8\pi} f_{D+}^2 |V_{cd}|^2 m_\ell^2 M_{D+} \left(1 - \frac{m_\ell^2}{M_{D+}^2}\right)^2$$

$$R_{\tau/\mu} = \frac{\Gamma(D^+ \to \tau^+ \nu_\tau)}{\Gamma(D^+ \to \mu^+ \nu_\mu)} = \frac{m_\tau^2 (1 - \frac{m_\tau^2}{M_{D+}^2})^2}{m_\mu^2 (1 - \frac{m_\mu^2}{M_{D+}^2})^2}$$

2.93 fb^{-1}

$D^+ \to \tau \nu$

$B_{\tau\nu}$: $(1.20 \pm 0.24 \pm 0.12) \times 10^{-3}$

using $B_{\mu\nu} = (3.74 \pm 0.17) \times 10^{-4}$

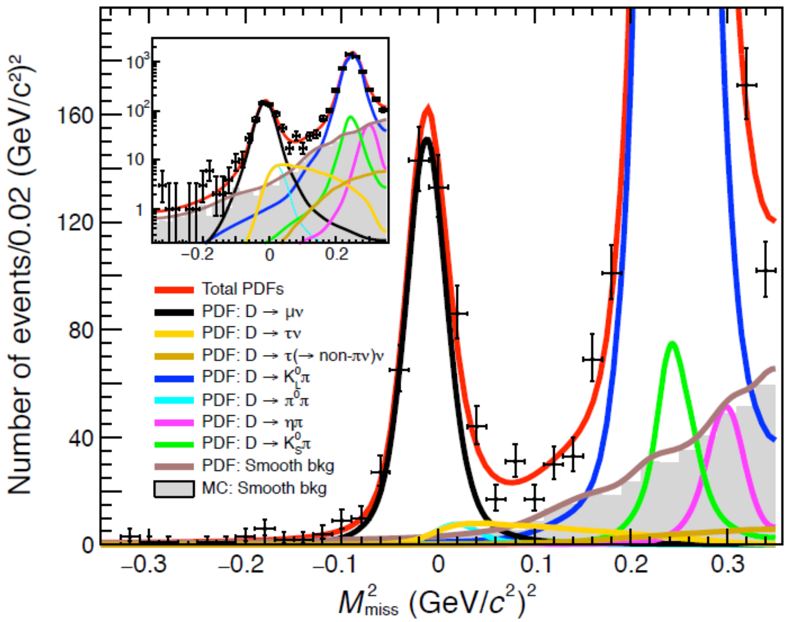
$R_{\tau/\mu} = 3.21 \pm 0.64 \pm 0.43$

Consistent with SM prediction 2.67

$f_{D+} = 224.5 \pm 22.8 \pm 11.3$ MeV

Consistent with LQCD prediction

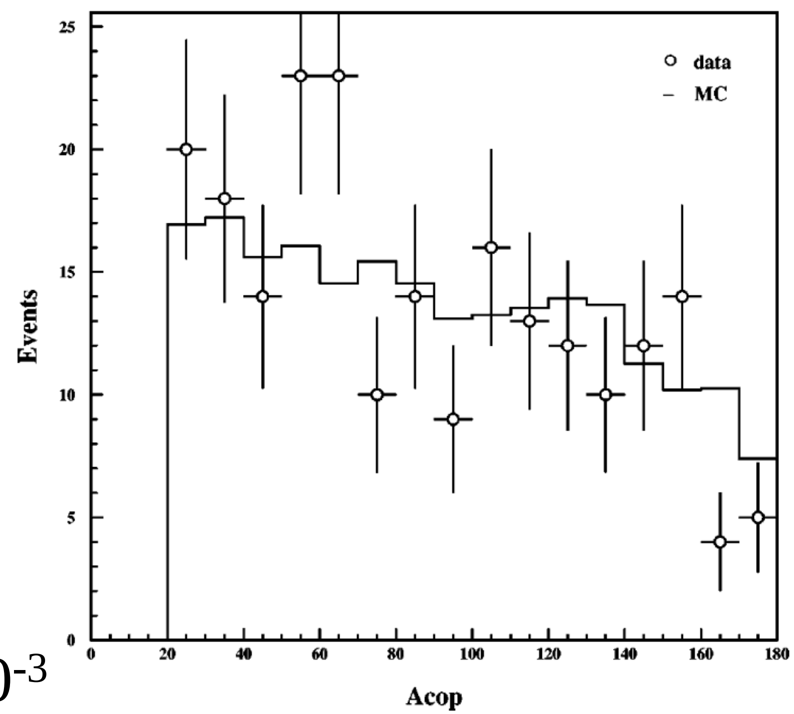
212.6 ± 0.6 MeV



ψ(2S)→ττ

- The ψ(2S) provides a unique opportunity to compare the three lepton generations by studying the leptonic decays ψ(2S)→ee,μμ,ττ

3.96M



$$\frac{B_{ee}}{v_e(\frac{3}{2}-\frac{1}{2}v_e^2)}=\frac{B_{\mu\mu}}{v_\mu(\frac{3}{2}-\frac{1}{2}v_\mu^2)}=\frac{B_{\tau\tau}}{v_\tau(\frac{3}{2}-\frac{1}{2}v_\tau^2)}$$

$$v_l=[1-(4m_l^2/M_{\psi(2S)}^2)]^{1/2}$$

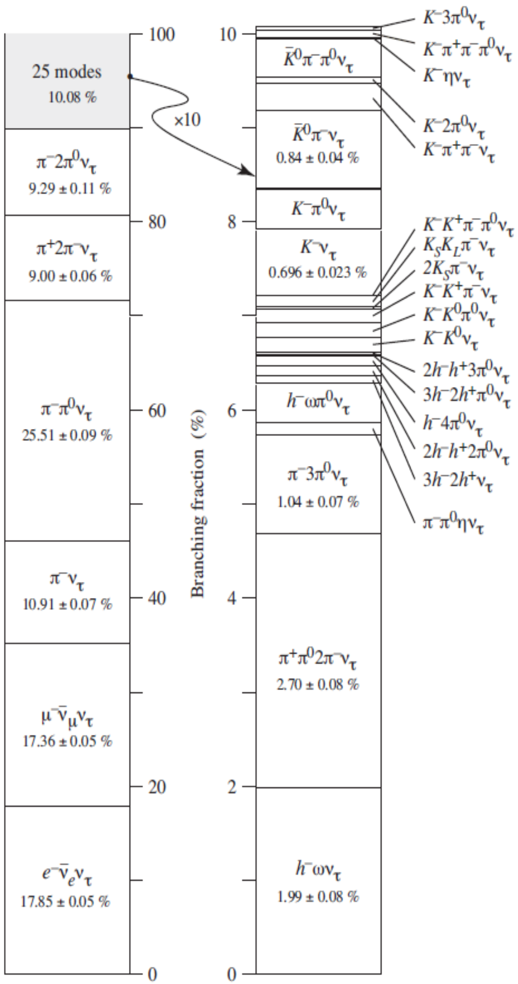
$$B_{ee}\simeq B_{\mu\mu}\simeq\frac{B_{\tau\tau}}{0.3885}\equiv B_{ll}$$

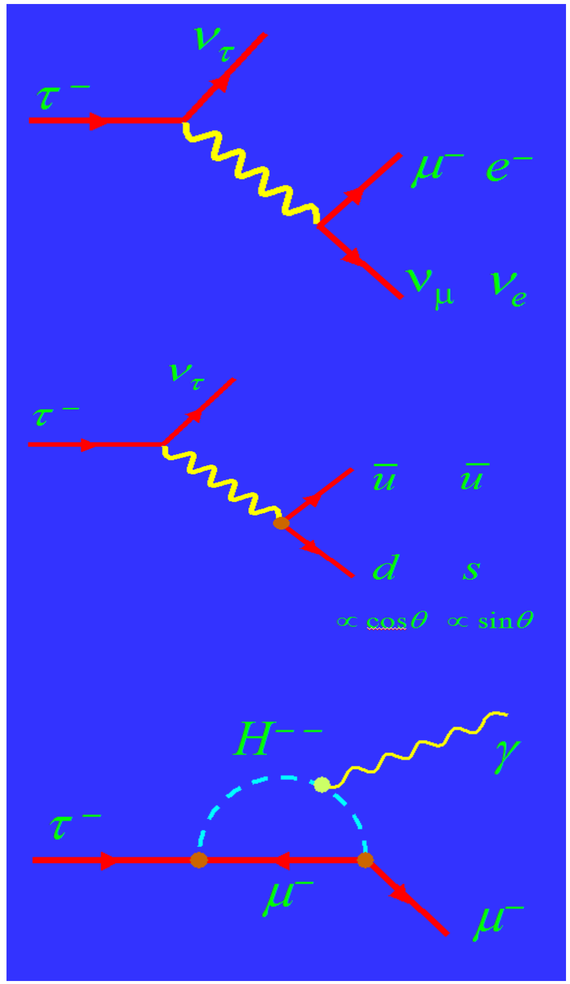
$$B_{\tau\tau}=(2.71\pm0.43\pm0.55)\times10^{-3}$$

$\boldsymbol{B_{\tau\tau}}$ /0.3885= $(7.0\pm1.1\pm1.4)\times10^{-3}$

SM prediction: $\boldsymbol{B_{ll}} = (8.4\pm1.0)\times10^{-3}$

Branch ratio of tau decay





- ❖ ***Pure leptonic***
  - $\tau^- \to \mu^- \nu_\mu \nu_\tau$ (<0.3%)
- ❖ ***Semi-leptonic***
  - ➢ ***Cabibbo favoured***
    - $\tau^- \to \pi^- \nu_\tau$ (<0.5%)
  - ➢ ***Cabibbo suppressed***
    - $\tau^- \to K^- \nu_\tau$ (<1.5 %)
- ❖ ***Rare and forbidden***
  - ➢ ***Lepton Flavor V***
    - $\tau^- \to \mu^- \gamma$ ($<10^{-8}$)
  - ➢ ***Lepton Number V***
    - $\tau^- \to \mu^+ \pi^+ \pi^-$ ($<10^{-8}$)
  - ➢ ***Baryon Number V***
    - $\tau^- \to \bar{p}\, \gamma$ ($<10^{-6}$)

Summary

- Mass of tau lepton has been measured in 2014, dominate the world average value

$$\mathbf{M_\tau = 1776.91 \pm 0.12 \, {}^{+0.10}_{-0.13} \; MeV}$$

- More precise measurement of mass of tau lepton (< 0.1 MeV) will be available soon
- More data are needed to study the tau decays to test the SM and beyond

Thank you for your attention!