Precision Measurement of τ lepton mass at BESIII

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Outline

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- BEPCII and BESIII
- Beam energy measurement system
- Data taking scenario
- Tau mass measurement at BESIII
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Motivation

- m_τ is a fundamental parameter of SM

$$\frac{B(\tau \to l\upsilon\bar{\upsilon})}{\tau_\tau} = \frac{g_\tau^2 m_\tau^5}{192\pi^3} F_{cor}(m_\tau, m_l)$$

  - Determination of m_τ to the highest possible precision → high precision test of the Standard Model.

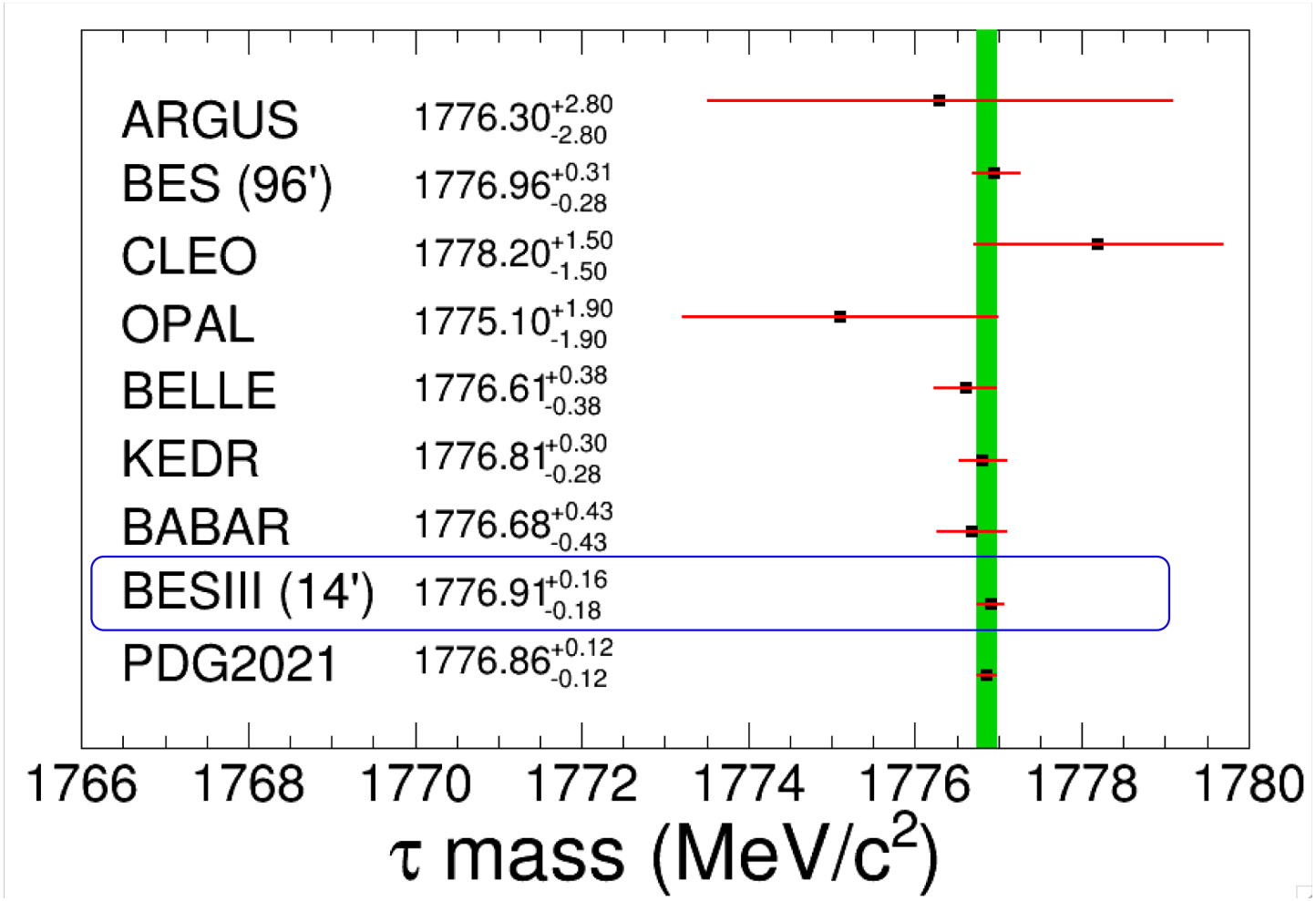
- Check lepton universality

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\tau_\mu}{\tau_\tau}\left(\frac{m_\mu}{m_\tau}\right)^5 \frac{B(\tau \to e\nu\bar{\nu})}{B(\mu \to e\nu\bar{\nu})} F_r = 1$$

Phys.R 421, 191 (2005)

  - Universality is sensitive to: m_τ^5
  - For e, μ, $\Delta m/m \sim 10^{-8}$, for τ, $\Delta m/m \sim 10^{-4}$, need more precise measurements.

Current status on τ mass measurement

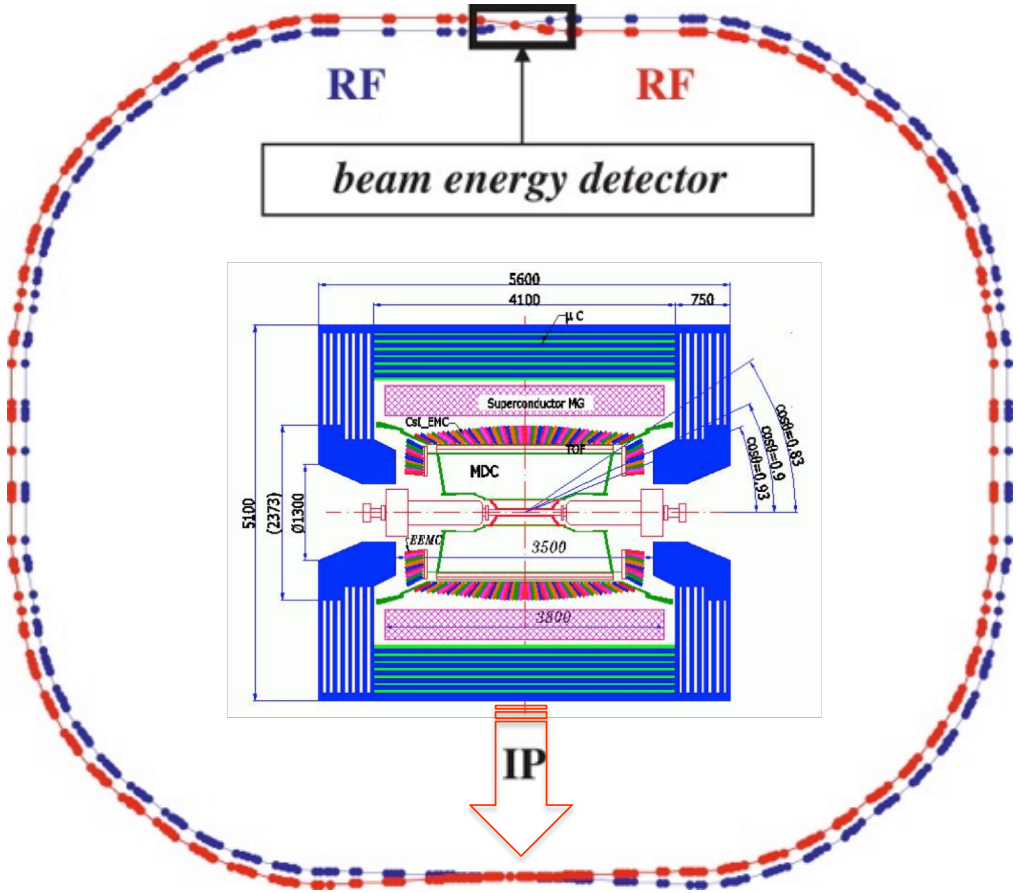


Beijing Electron Positron Collider (BEPCII)

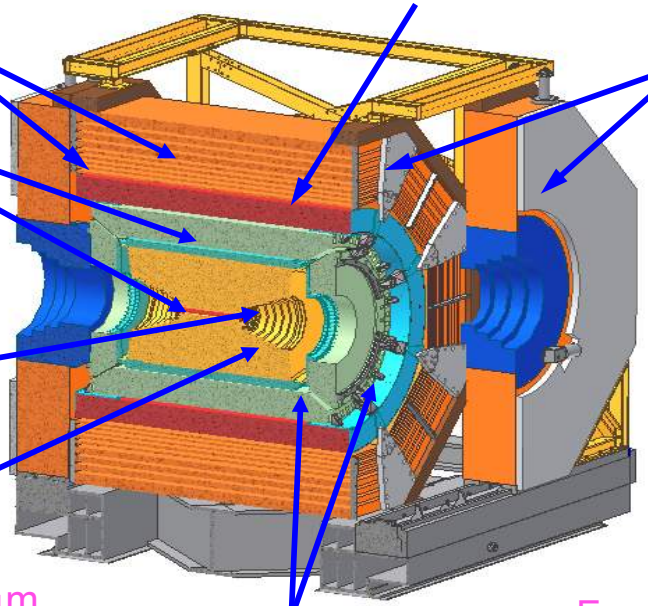
- Beam energy: 1.0 ~ 2.3 GeV
- Double-ring structure
- 2004: started BEPCII upgrade, BESIII construction
- 2009 -now: BESIII physics run
- 1989-2004 (BEPC):

  $L_{peak} = 1.0 \times 10^{31}\ cm^{-2}s^{-1}$
- 1989-2004 (BEPC):

  $L_{peak} = 1.0 \times 10^{33}\ cm^{-2}s^{-1}$ (4/5/2016)

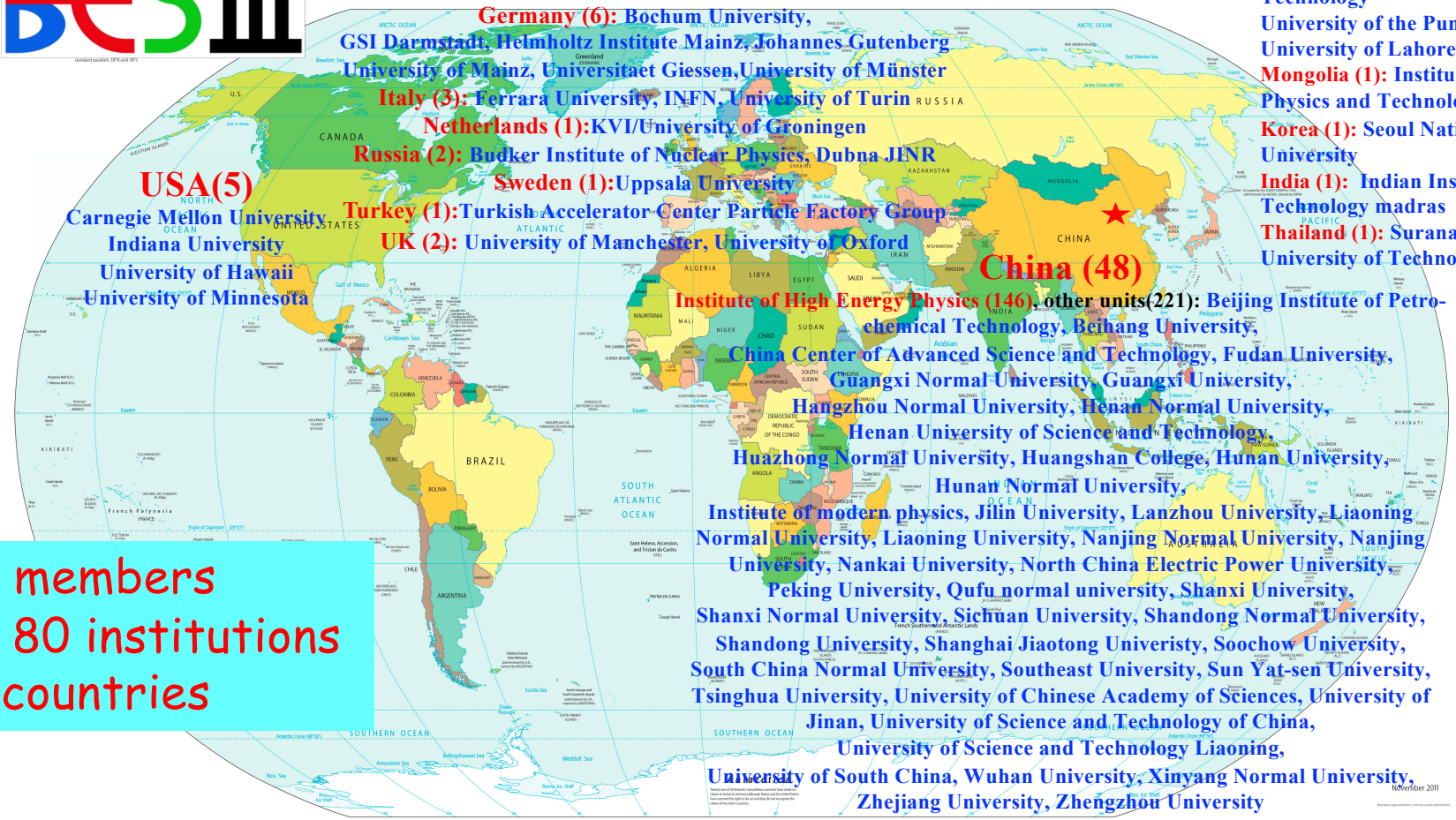


BESIII Detector



Int. J. Mod. Phys. A24, 377 (2009)
NIM A614, 345 (2010)

The BESIII Collaboration



Europe (17)

Germany (6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen, University of Münster

Italy (3): Ferrara University, INFN, University of Turin

Netherlands (1): KVI/University of Groningen

Russia (2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden (1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK (2): University of Manchester, University of Oxford

USA(5)

Carnegie Mellon University

Indiana University

University of Hawaii

University of Minnesota

Asia (6)

Pakistan (2): COMSATS Institute of Information Technology

University of the Punjab, University of Lahore

Mongolia (1): Institute of Physics and Technology

Korea (1): Seoul National University

India (1): Indian Institute of Technology madras

Thailand (1): Suranaree University of Technology

China (48)

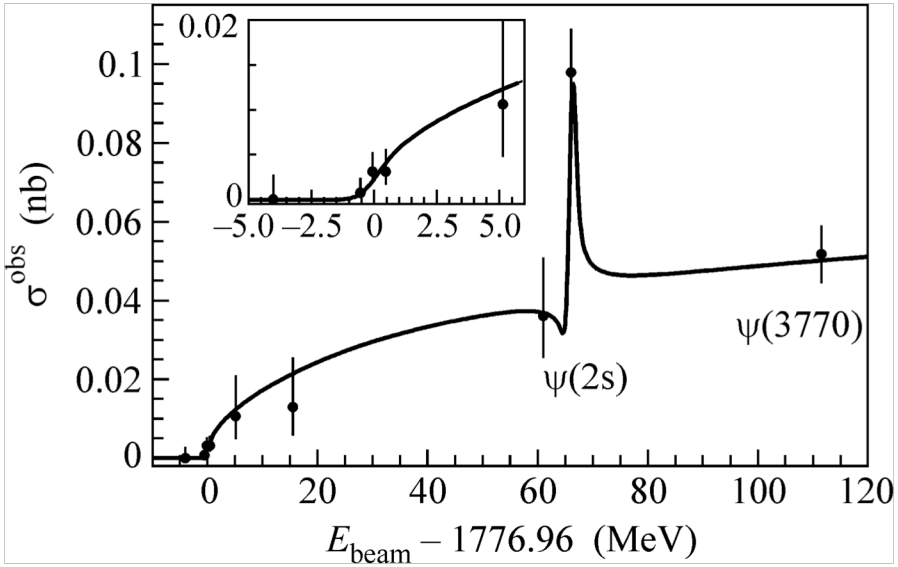
Institute of High Energy Physics (146), other units(221): Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Institute of modern physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu normal university, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiaotong Univeristy, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Zhejiang University, Zhengzhou University

~500 members
From 80 institutions
in 17 countries

Threshold scan method

- Study of the threshold behavior of the τ pair production cross section in e^+e^- collisions
- Extremely important is to determine the beam energy and the beam energy spread precisely

Observed $\tau^+\tau-$ cross section versus the beam energy



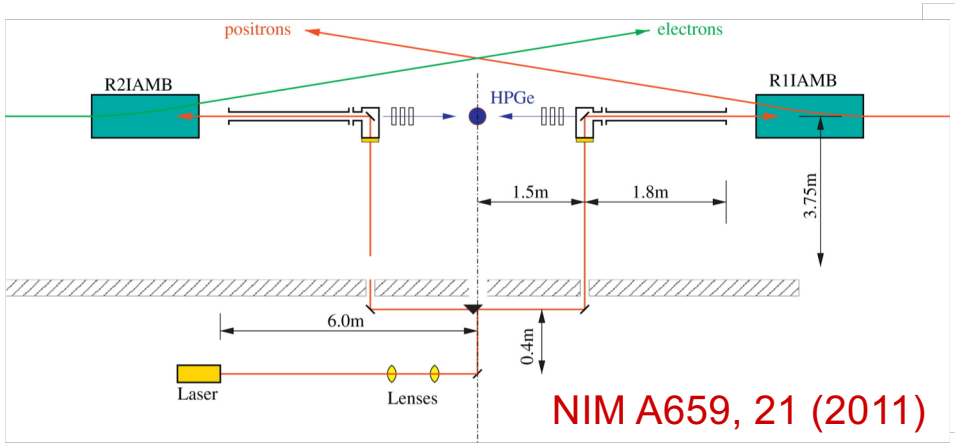
KEDR detector
JETPL 85, 347

Beam Energy Measurement System (BEMS)

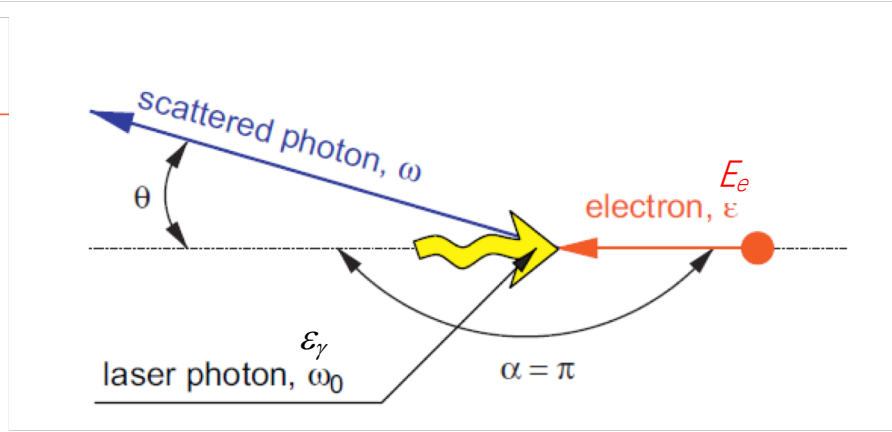
- Determination of beam energy crucial for τ mass measurement
- The electron energy E_e is related to the maximal energy of the scattered photon E_γ by the kinematics of Compton scattering

$$E_e = \frac{E_\gamma}{2}\left[1+\sqrt{1+\frac{m_e^2}{\varepsilon_\gamma E_\gamma}}\right] \Rightarrow E_{CM} = 2\times\sqrt{\overline{E}_{e^+}\times\overline{E}_{e^-}}\times\cos\left(\frac{\theta_{e^+e^-}}{2}\right)$$

- σ(Energy) ~ 10^{-5}, Δ (Energy spread) / Energy spread ~ 6%



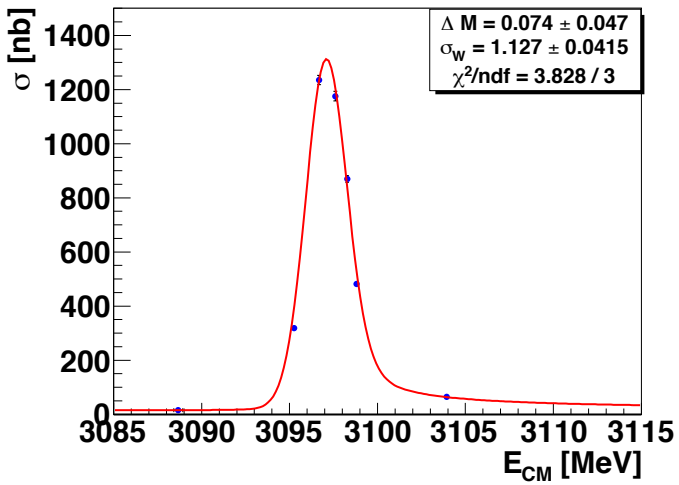
NIM A659, 21 (2011)

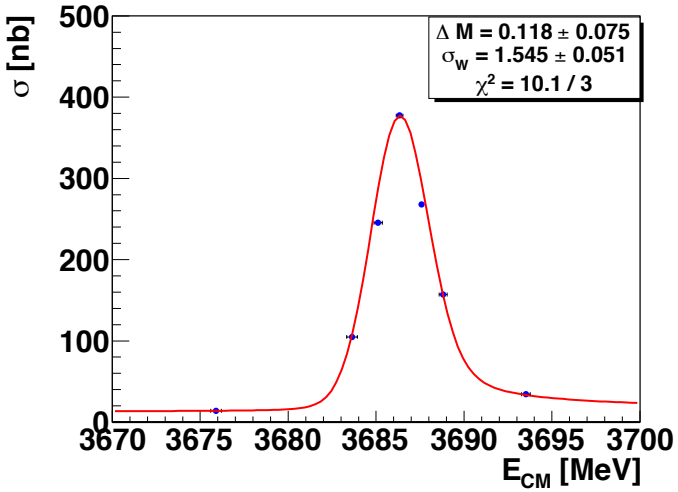


Data taking scenario

Three stages:

- J/ψ scan for BEMS calibration and beam energy spread measurement
- τ mass scan near tau threshold
- ψ' scan for BEMS calibration and beam energy spread measurement





τ mass scan at BESIII in 2011

- The likelihood function for the maximum likelihood fitting:

$$L(m_\tau, R_{Data\,/\,MC}, \sigma_B) = \prod_{i=1}^{4} \frac{\mu_i^{N_i} e^{-\mu_i}}{N_i!},$$

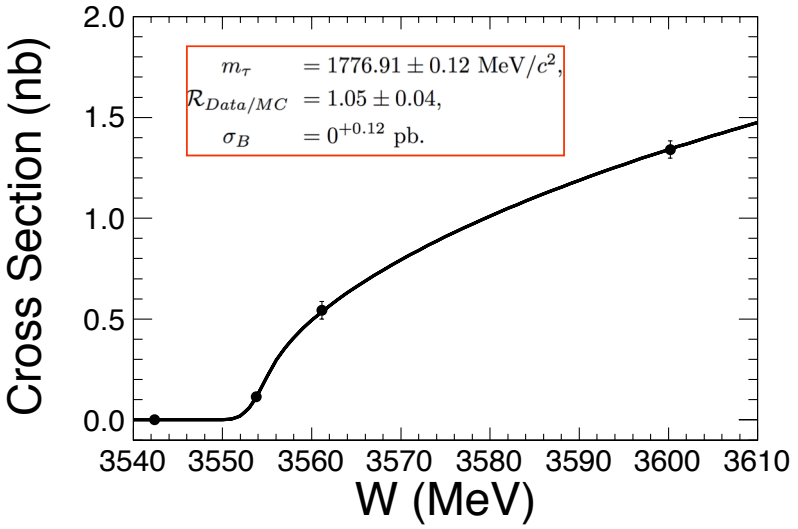
$$\mu_i = [R_{Data/MC} \times \varepsilon_i \times \sigma(E_{CM}^i, m_\tau) + \sigma_B] \times l_i$$

$$\varepsilon_i = Br_j \varepsilon_{ij},$$

i represents energy points, j represent channels

- In carrying out the ML fit, m_τ , $R_{data/MC}$, σB are free parameters

The CM energy dependence of the τ pair cross section resulting from the likelihood fit (curve), compared to the data (Poisson errors)



Systematic errors	
Source	keV
Theo.	10
E_{Spread}	16
E_{Scale}	+22 -86
$E_{Selection}$	50
Eff.	48
Bg. shape	40
Lum.	6
Sum	+100 -130

$$m_\tau = 1776.91 \pm 0.12(stat.)^{+0.10}_{-0.13}(sys.)\ \text{MeV}$$

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = 1.0016 \pm 0.0042$$

PRD 90, 012001 (2014)

Prospect on the new τ mass scan in 2018

	J/ψ (pb^{-1})	ψ' (pb^{-1})	τ Mass scan(pb^{-1})					
			3540MeV	3552MeV	3553MeV	3560MeV	3600MeV	total
2011	15	7.5	4.3	0	5.6	3.9	9.6	23.4
2018	31.7	67.9	23.8	69.7	9.2	15.0	14.9	138.3

- Data analysis on the new τ mass scan in 2018 is ongoing
- $\sigma_{stat.}$ is expected to be around 50KeV.
- $\sigma_{sys.}$ is expected to be the same level as $\sigma_{stat.}$
- New result is coming soon.

Summary

- In order to check lepton universality precisely, more precise measurement of τ mass is required.

- Thanks to the BEMS and the new τ threshold scan data collected at BESIII in 2018, the uncertainty of tau mass measurement at BESIII is expected to be less than 100KeV.

- New result from the new data is coming soon.