Lepton Universality and τ Lepton Mass Measurement

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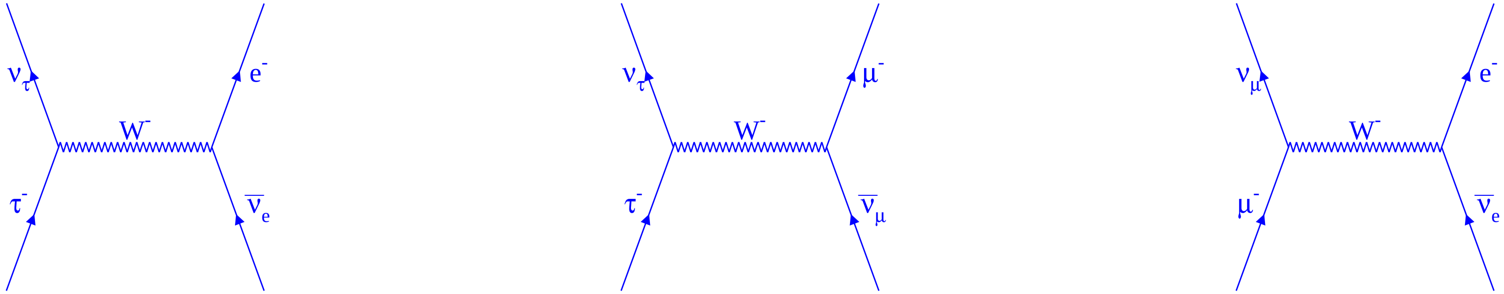
Outline

1. τ lepton and lepton universality
2. τ mass at KEDR
3. τ mass at Belle
4. Conclusions

General

- During last two decades Standard Model (SM) successfully survived a lot of different tests
- First checked with electrons and muons, SM tests should also involve τ leptons
- τ lepton may decay into both leptons and hadrons, we can study all interactions allowed in the SM and search for effects of New Physics
- One of the SM intrinsic features is flavor independence of the Fermi constant, $G_{\rm F}$
- B factories are a unique and extremely copious source of $\tau^+\tau^-$ pairs providing about 0.9×10^6 events per 1 fb^{-1}

Leptonic Universality in Leptonic Decays – I



$$\Gamma(L \to l\nu_L\bar{\nu}_l) \;=\; \frac{G_L^2\ m_L^5}{192\pi^3} F_{\rm cor}(m_L, m_l)$$

$$F_{\rm cor}(m_L, m_l) = f(m_l^2/m_L^2)\ F_{\rm W}\ F_{\rm rad}$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 lnx$$

$$F_{\rm W} = 1 + \frac{3}{5}\frac{m_l^2}{m_W^2}, \qquad F_{\rm rad} = 1 + \frac{\alpha(m_L)}{2\pi}\left(\frac{25}{4} - \pi^2\right)$$

Lepton universality: $G_e = G_\mu = G_\tau = G_{\rm F}$

Lepton Universality in Leptonic Decays – II

$$r = \left(\frac{G_\tau}{G_\mu}\right)^2 = \left(\frac{G(\tau^- \to e^- \nu_\tau \bar{\nu}_e)}{G(\mu^- \to e^- \nu_\mu \bar{\nu}_e)}\right)^2 = (\frac{m_\mu}{m_\tau})^5 (\frac{t_\mu}{t_\tau}) \mathcal{B}(\tau \to e \nu_\tau \bar{\nu}_e) \frac{F_{\rm cor}(m_\mu, m_e)}{F_{\rm cor}(m_\tau, m_e)}$$

Correction	μ	τ
$f(m_e^2/m_L^2)$	0.9998	1.0000
$F_{\rm W}(m_L)$	1.0000	1.0003
$F_{\rm rad}(m_L)$	0.9958	0.9957
Total	0.99558	0.99597

Lepton universality $\Rightarrow r = 1$

Two Methods of m_τ Measurement

- Energy dependence of $\sigma(e^+e^- \to \tau^+\tau^-)$ near threshold

$$\sigma_0 = \sigma(e^+e^- \to \tau^+\tau^-) \ = \ 86.85 \ (\mathrm{nb})/\mathrm{s}(\mathrm{GeV}^2) \ \sqrt{1 \ - \ 4m_\tau^2/s} \ (1 \ + \ 2m_\tau^2/s).$$

First used by DELCO in 1978

- Pseudomass

Reconstruction of the invariant mass and energy of the hadronic system in hadronic τ decays

Suggested and first used by ARGUS in 1992

History of m_τ Measurements

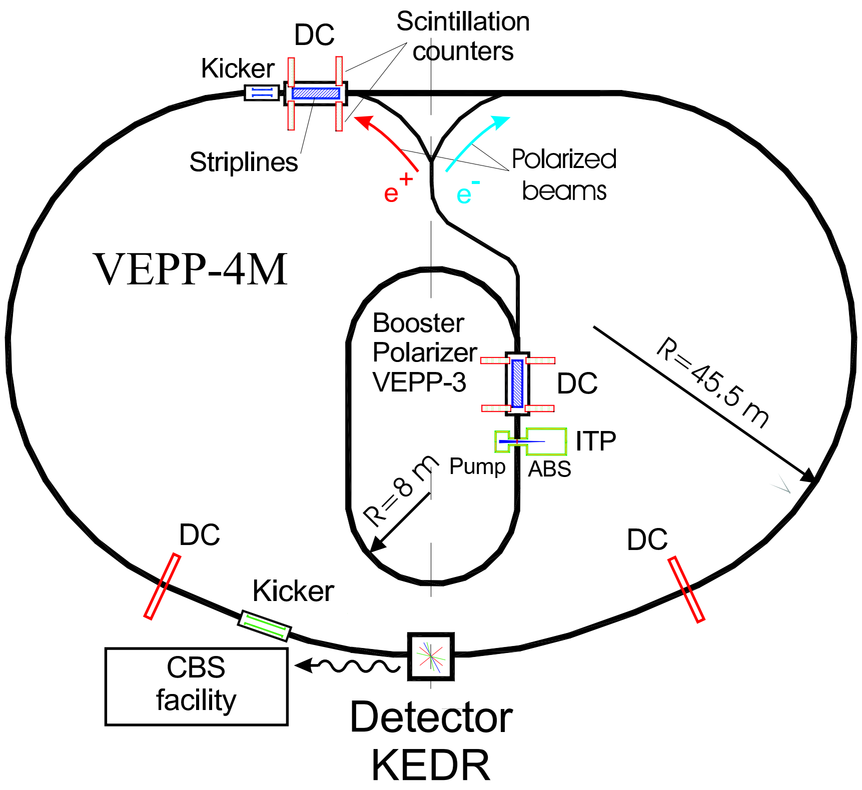
m_τ, MeV	N_{ev}	Group	$\sqrt{s}$, GeV	Method
1783^{+3}_{-4}	692	DELCO, 1978	$3.1 - 7.4$	σ
$1776.3 \pm 2.4 \pm 1.4$	$11k$	ARGUS, 1992	$9.4 - 10.6$	P/m
$1776.96^{+0.18+0.25}_{-0.21-0.17}$	65	BES, 1996	$3.54 - 3.57$	σ
$1778.2 \pm 0.8 \pm 1.2$	$98.5k$	CLEO, 1997	10.6	P/m
$1775.1 \pm 1.6 \pm 1.0$	$13.3k$	OPAL, 2000	~ 90	P/m
$1776.99^{+0.29}_{-0.26}$		PDG, 2006		

Test of Lepton Universality in Leptonic Decays

$$r = \left(\frac{G_\tau}{G_\mu}\right)^2$$

r	t_τ, fs	$\mathcal{B}(\tau \to e\nu_\tau\bar{\nu}_e)$, %	m_τ, MeV	Comments
0.9405 ± 0.0249	305.6 ± 6.0 ± 0.0185	17.93 ± 0.26 ± 0.0136	$1784.1^{+2.7}_{-3.6}$ $^{+0.0071}_{-0.0095}$	PDG, 1992 -2.4σ
0.9999 ± 0.0069	291.0 ± 1.5 ± 0.0052	17.83 ± 0.08 ± 0.0045	$1777.0^{+0.30}_{-0.27}$ ± 0.0008	PDG, 1996 -0.01σ
1.0020 ± 0.0051	290.6 ± 1.1 ± 0.0038	17.84 ± 0.06 ± 0.0034	$1776.99^{+0.29}_{-0.26}$ ± 0.0008	PDG, 2004 $+0.4\sigma$

VEPP-4M: General Layout



Physics at VEPP-4M

- $\sqrt{s}$ from 2 to 11 GeV
- Originally designed for b quark physics
  is now running in the charmonium region
- $L_{\rm max} = 2 \times 10^{30}$ cm^{-2}s^{-1} at 1.78 GeV
- Properties of ψ family states, 2γ physics
- High-precision mass measurements (J/ψ, $\psi(2S)$, τ) based on
  two independent methods of energy determination:
  Resonant depolarization for absolute calibration (slow)
  Compton backscattering of laser 0.12 MeV photons (fast)

Resonant Depolarization – I

Usual NMR based absolute energy determination – $3 \cdot 10^{-4}$

Resonant depolarization suggested at BINP in 1975

gives at least an order of magnitude better precision

In a storage ring with a flat orbit:

$$\Omega/\omega_0 = 1 + \gamma \cdot \mu'/\mu_0,$$

Ω – spin precession frequency, ω_0 – revolution frequency,

μ'/μ_0 – the ratio of the anomalous (normal) parts of emm known with an accuracy of 10^{-9}

The average ω_0 is determined by the RF frequency of the guiding field and can be set and determined with high accuracy

Ω is measured at the moment of depolarization by the external electromagnetic field with a frequency ω_d:

$$\omega_\mathrm{d} \pm \Omega = k\omega_0$$

Resonant Depolarization – II

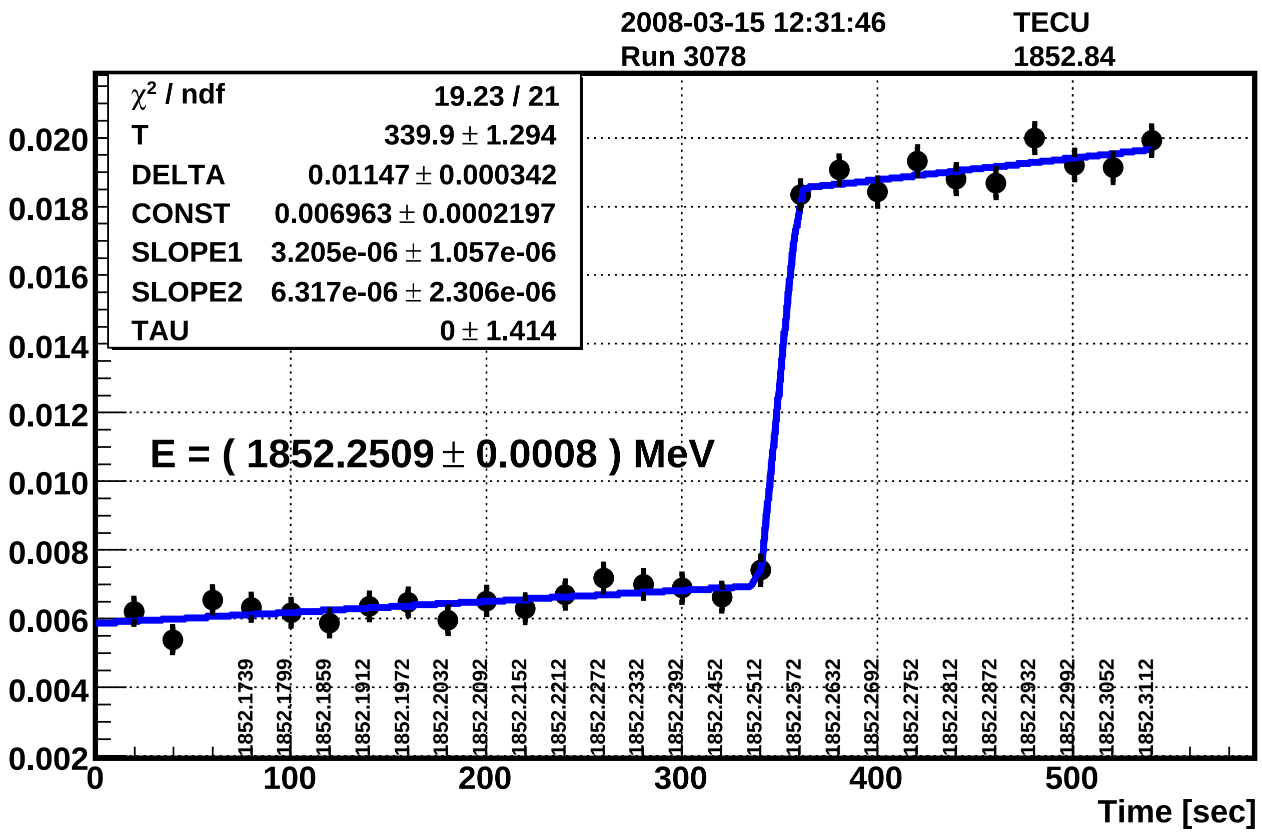
Since 1975 has been successfully used
to determine masses of various particles:
$K^{\pm}$, ω, ϕ, J/ψ, $\psi(2S)$, $\Upsilon(3S)$ at BINP,
$\Upsilon(1S)$ at BINP and Cornell, $\Upsilon(2S)$ at BINP and DESY, Z at CERN
Also used at various SR facilities

State	Mass, MeV/c^2	$\Delta m/m$	Factor
ϕ	1019.455 ± 0.020	$2.0 \cdot 10^{-5}$	25
J/ψ	3096.916 ± 0.011	$3.6 \cdot 10^{-6}$	90
$\Upsilon(1S)$	9460.30 ± 0.26	$2.7 \cdot 10^{-5}$	50
Z	91187.6 ± 2.1	$2.3 \cdot 10^{-5}$	60

Resonance Depolarization – III

- The beams get polarized at $E_{\rm beam} = 1772$ MeV, the polarization lifetime is ≤ 1000 s, the polarized beam is injected to VEPP-4M, 10 minutes later an unpolarized beam is added as a second bunch
- Touschek (intrabeam scattering) effect is used to detect the moment of depolarization; the cross section of polarized electrons is smaller than that for unpolarized particles
- The transverse wave with the magnetic field perpendicular to the polarization is used as a depolarizer, the depolarization time is about 2 s
- The counting rate of the polarimeter is 1 MHz at beam currents of 2-4 mA
- The process of RD energy calibration lasts about 2 hours and is performed once a day, more than 1500 calibrations were performed since 2002

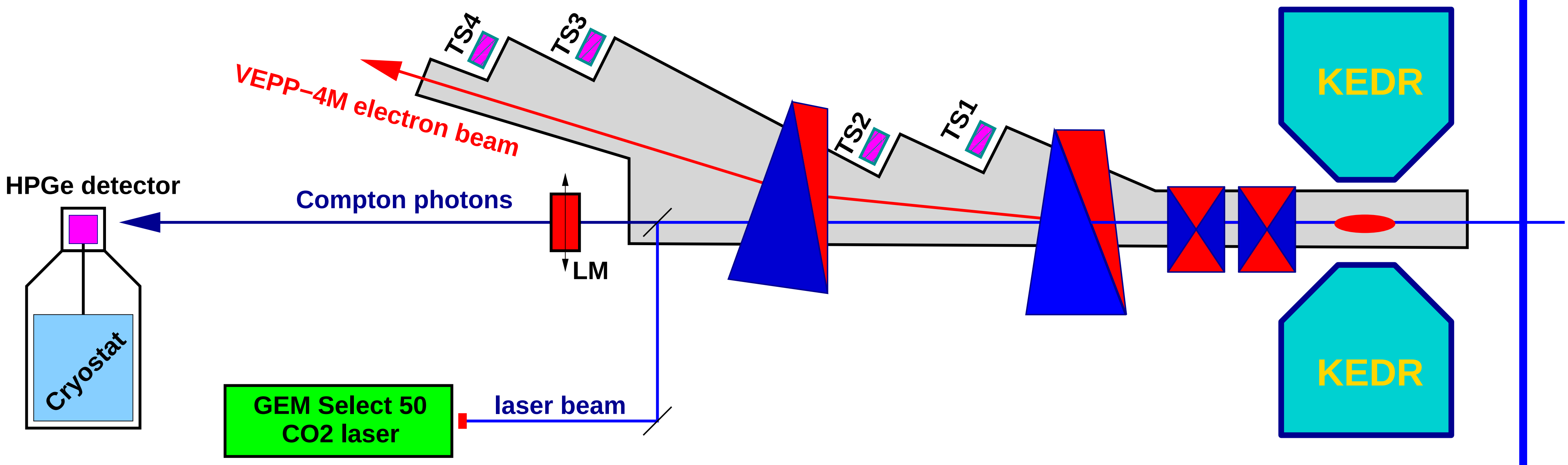
Typical RD Run at VEPP-4M



The resonant depolarization (RD) once a day with $\sigma_E < 20$ keV

Compton Backscattering Monitor

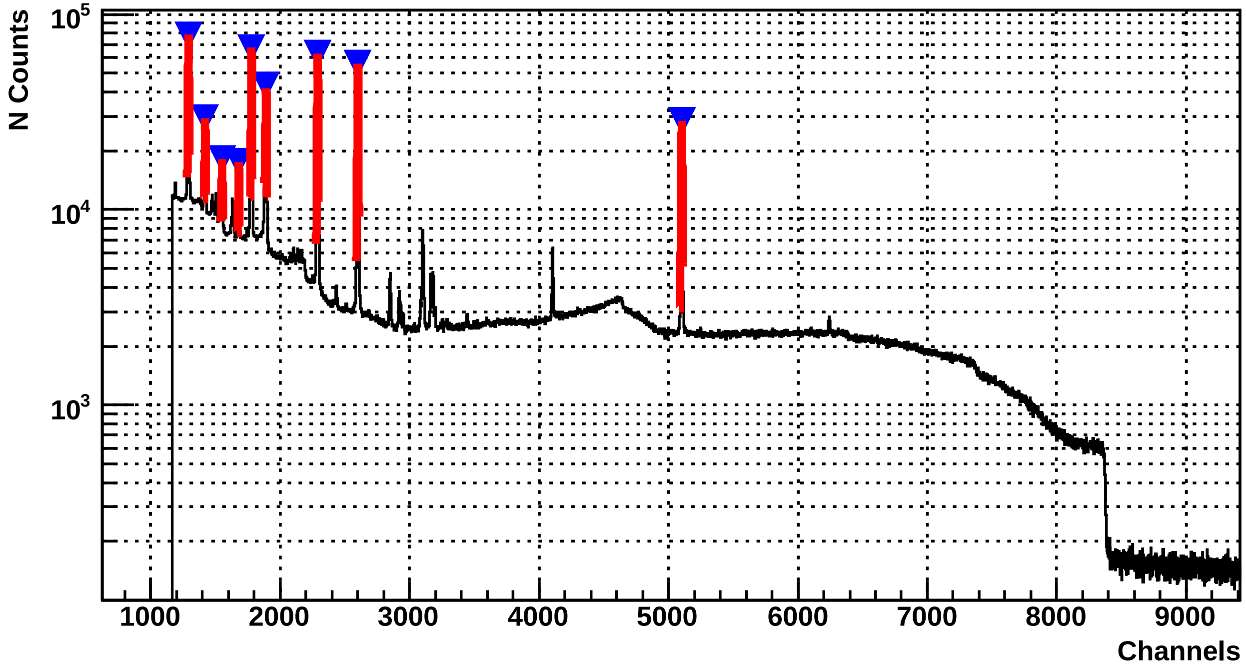
Realized at BESSY-I in 1987



A carbon dioxide laser is used, $\lambda = 10.591\ \mu$m ($\omega_0 = 0.117$ eV)

$\omega_{\rm max}$ =1-7 MeV, $\Delta\omega_0/\omega_0 = 10^{-7}$, cont. power of 30 W

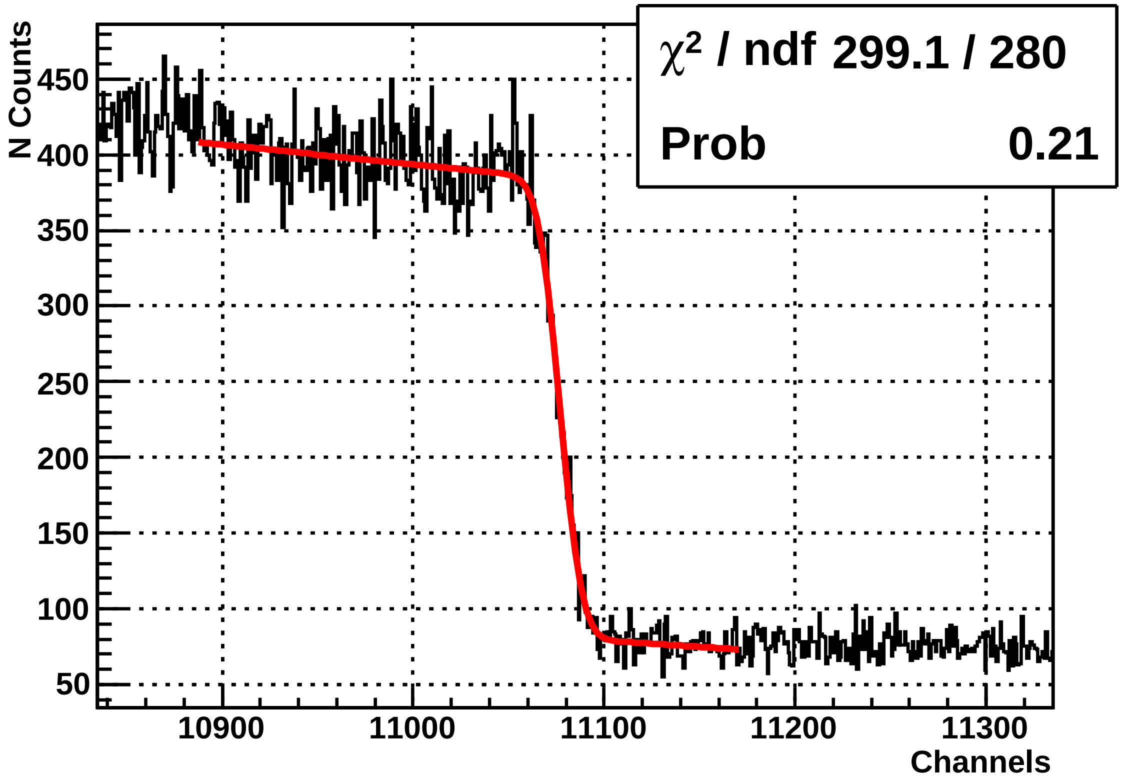
Spectrum of CBS Photons with Calibration Lines



A High Purity Germanium (HPG) detector, $V_{\rm act} = 120$ cm^3, $\epsilon = 5\%$ at 6 MeV, internal resolution $(0.6 + 0.2\omega[\rm MeV])$ keV, the pile-up noise is (1-3) keV

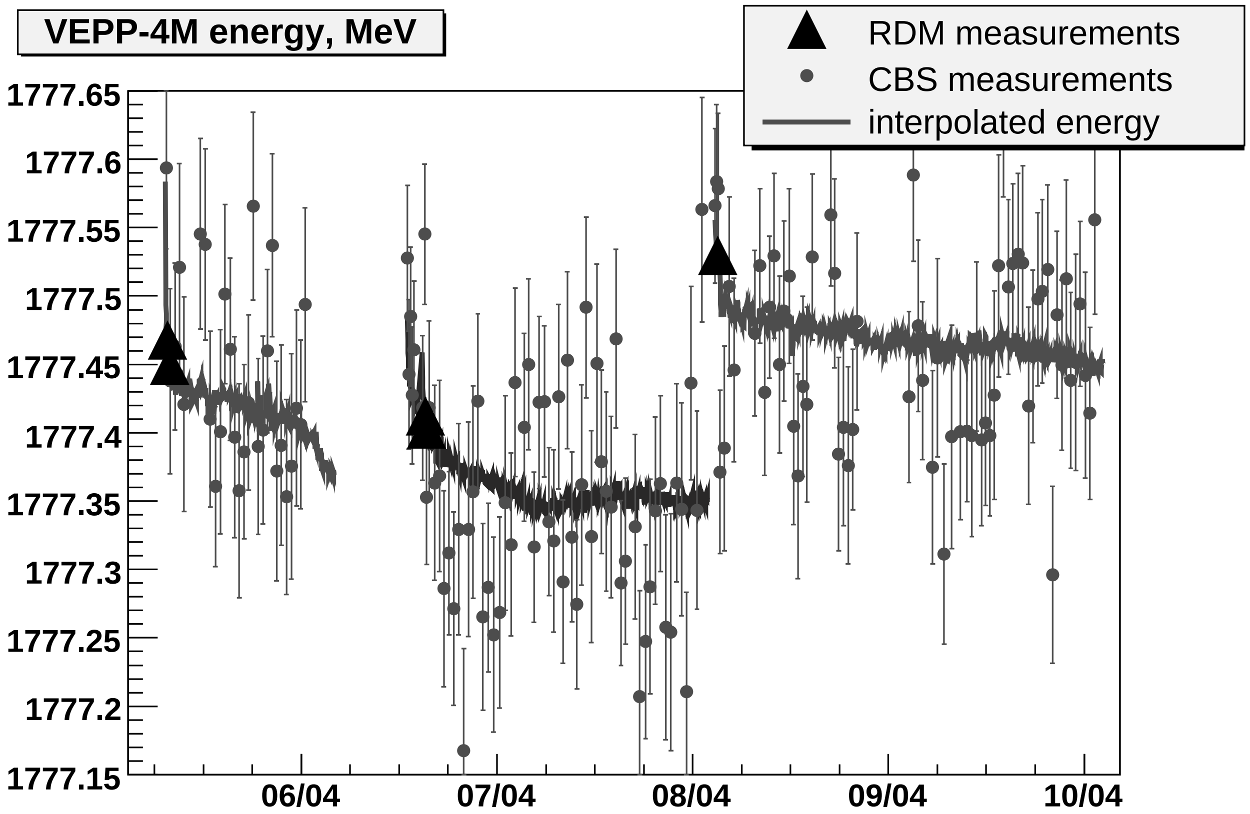
HPG calibrated with γ sources in the 0.5-2.7 MeV range and extr. to $\omega_{\rm max}$

Typical CBS Spectrum Edge at VEPP-4M



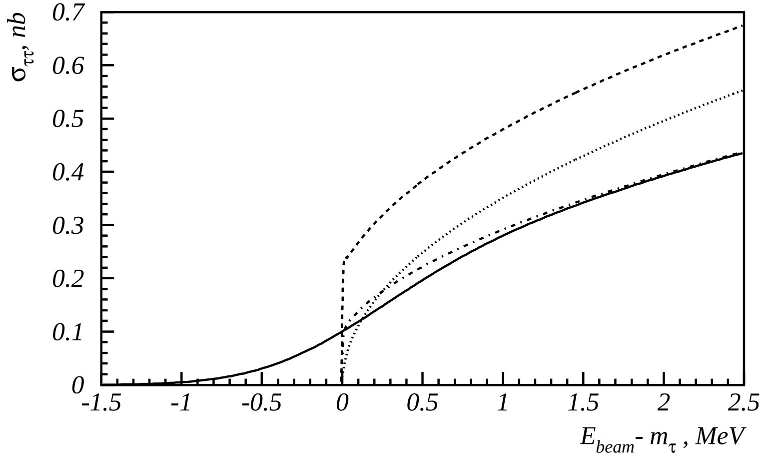
Between the RD, the Compton backscattering (CBS) with $\sigma_E \approx 100$ keV

VEPP-4M Energy Behaviour



During the run, E measured by CBS, then interpolation

$\sigma(e^+e^- \to \tau^+\tau^-)$ Near Threshold



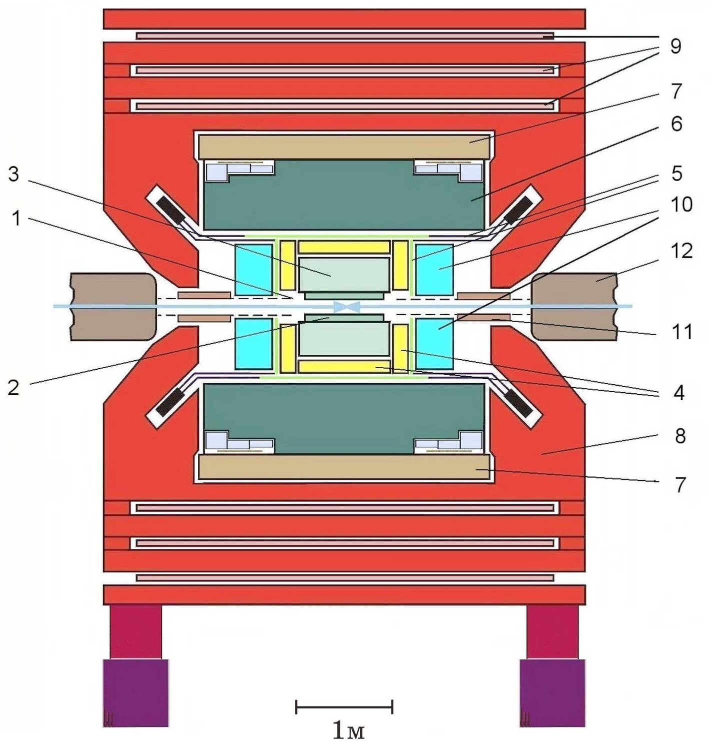
$$\sigma(W) = \frac{1}{\sqrt{2\pi}\sigma_W} \int dW' \exp\left\{-\frac{(W-W')^2}{2\sigma_W^2}\right\} \int dx\, F(x,W')\, \sigma_{fs}(W'\sqrt{1-x}),$$
$$\sigma_{fs}(W) = \sigma_0(W) F_c(\beta) F_r(W) / |1-\Pi(W)|^2$$

$$F_c(\beta) = (\pi\alpha/\beta)/(1-\exp(-\pi\alpha/\beta)), \quad \beta = (1-(2m_\tau/W)^2)^{1/2}$$

Dotted – Born, dashed – Coulomb, FSR and VP,

dash-dotted – ISR, solid – beam energy spead

KEDR Detector



1) Vacuum chamber, 2) Vertex detector,

3) Drift chamber, 4) Aerogel counters,

5) ToF–counters, 6) LKr calorimeter,

7) Superconducting coil, 8) Magnet yoke,

9) Muon tubes, 10) CsI calorimeter,

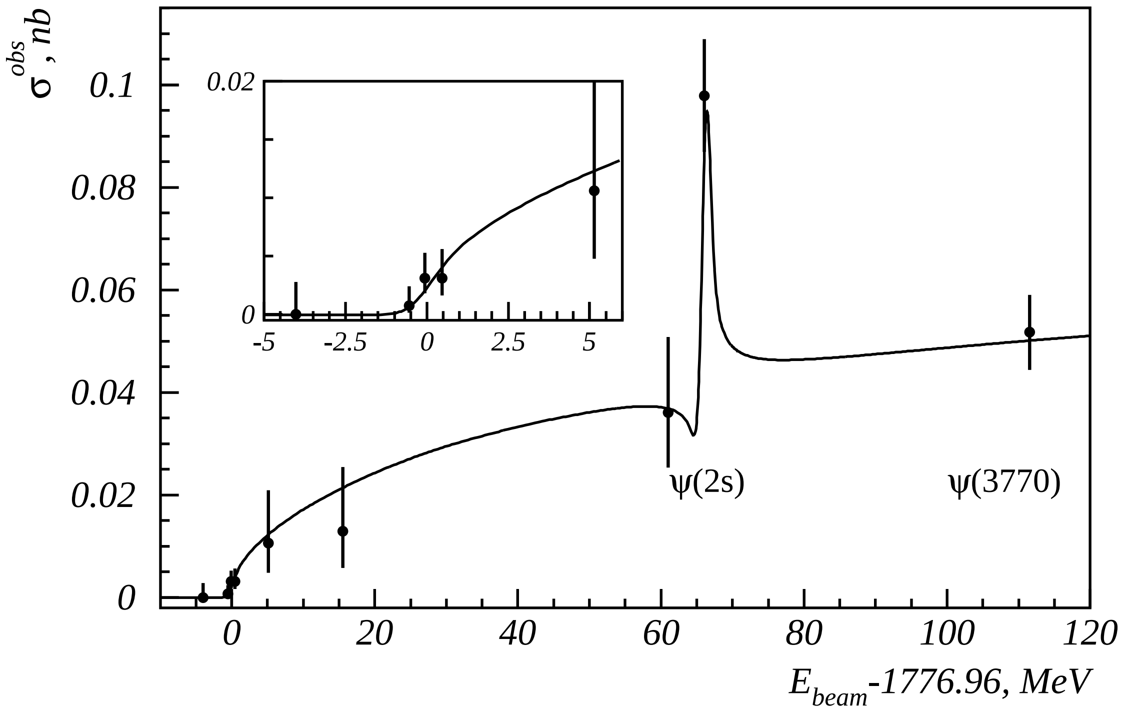
11) Compensation solenoid,

12) VEPP–4M quadrupole

m_τ at KEDR: Summary of the scan

Point	$< E >$, MeV	$\int Ldt$, nb^{-1}	$N_{\tau\tau}$	$\sigma^{obs}_{\tau\tau}$, pb
1	1771.945 ± 0.160	668	0	$0.0^{+2.8}_{-0.0}$
2	1776.408 ± 0.086	1382	1	$0.7^{+1.7}_{-0.6}$
3	1776.896 ± 0.045	1605	6	$3.7^{+2.2}_{-1.5}$
4	1777.419 ± 0.061	1288	4	$3.1^{+2.5}_{-1.5}$
5	1782.103 ± 0.060	283	4	$14.1^{+11.3}_{-6.8}$
6	1792.457 ± 0.102	233	3	$12.9^{+12.5}_{-7.1}$
7	1837.994 ± 0.092	305	14	$45.8^{+16.0}_{-12.2}$
8	1843.040 ± 0.065	807	79	97.9 ± 11.0
9	1888.521 ± 0.228	967	49	50.7 ± 7.2
Total	Without $\psi(2S)$	6731	81	

m_τ at KEDR: Observed $\sigma(e^+e^- \to \tau^+\tau^-)$



$\int Ldt = 6.7\ \text{pb}^{-1}$, 81 events selected

$m_\tau = 1776.81^{+0.25}_{-0.23}\ \text{MeV}/c^2$, $\epsilon = (2.25 \pm 0.28)\%$, $\sigma_B = 0^{+0.58}_{-0.00}$ pb.

m_τ at KEDR: Systematic Uncertainties – I

- Interpolation takes into account guiding field measurements, ring and tunnel temperature variations – 40 keV
- Detector efficiency variations (MC model, selection criteria, performance of subsystems) – 100 keV
- Beam energy spread (from $\sigma_W(J/\psi)$ and $\sigma_W(\psi(2S)$ and assuming linear growth $\sigma_W(2m_\tau) = (1.07 \pm 0.02 \pm 0.04)$ MeV) – 25 keV
- Background (variation of shape, possible energy dependence) – 20 keV
- Instability of luminosity measurement (comparison of LKr and CsI) – 90 keV
- Calculation of $\sigma(e^+e^- \to \tau^+\tau^-)$ (rad. corrections, interference) – 30 keV

m_τ at KEDR: Systematic Uncertainties – II

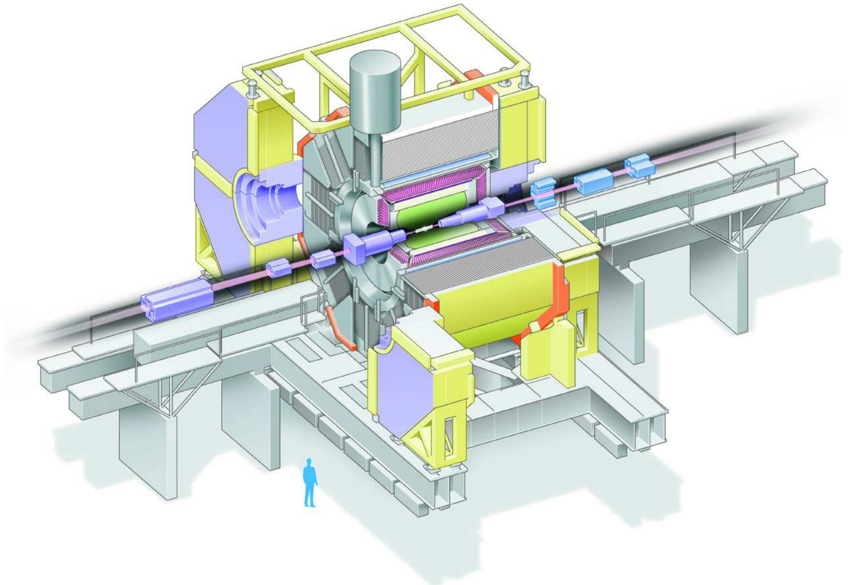
Source	σ, keV/c^2
Beam energy	40
Detection efficiency	100
Energy spread accuracy	25
BG energy dependence	20
Luminosity measurement	90
Energy spread variation	15
Cross section	30
Total	150

$m_\tau = 1776.81^{+0.25}_{-0.23} \pm 0.15$ MeV/c^2

V.V. Anashin et al., JETP Letters 85, 347 (2007)

KEKB and Belle Detector

- 3.5 GeV $e^+ \times$ 8.0 GeV e^-
- $\mathcal{L}_{\max} = 1.71 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Continuous injection $\to$ **1.2 fb^{-1}**/day
- $\int \mathcal{L}dt \approx 852\ \mathrm{fb}^{-1}$

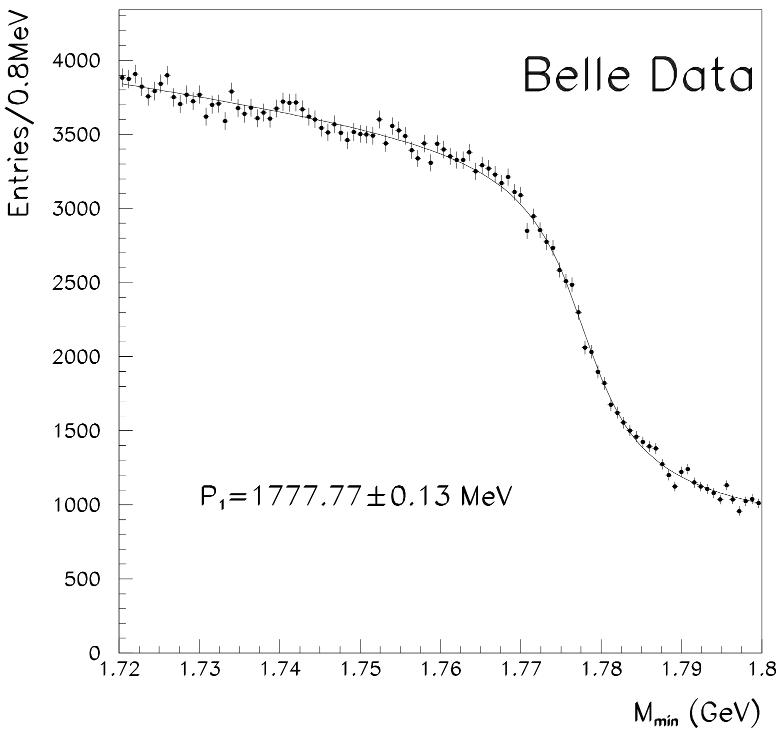


- Sil.VD: 3(4) layers DSSD
- CDC : small cells $He + C_2H_6$
- TOF counters
- Aerogel CC:$n = 1.015 \sim 1.030$
- CsI(Tl) 16 X_0
- SC solenoid 1.5 T
- μK_L detection 14-15 layers RPC+Fe

m_τ at Belle: Pseudomass

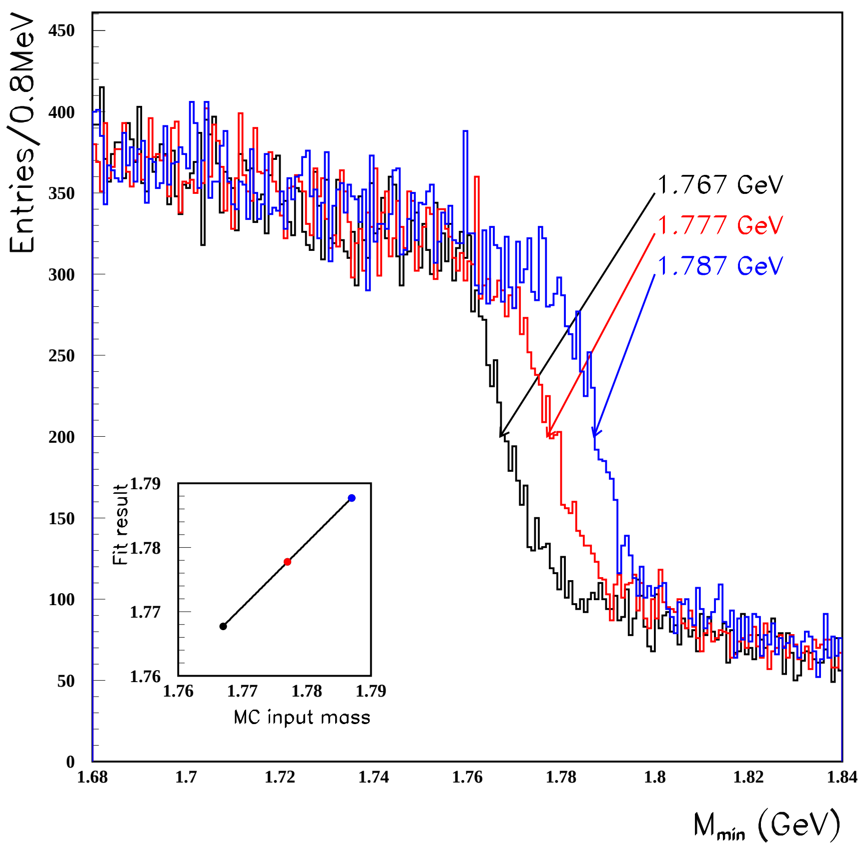
- 414 fb^{-1} or 370×10^6 $\tau^+\tau^-$ pairs
- $\sim 5.8 \cdot 10^6$ events $\tau^- \to \pi^+\pi^-\pi^-\nu_\tau$
- $p_\tau = p_X + p_\nu \Rightarrow m_X^2 + m_\nu^2 + 2(E_X E_\nu - |\vec{p}_X||\vec{p}_\nu| cos\theta)$
- $m_\nu = 0,\ |\vec{p}_\nu| = E_\nu = E_\tau - E_X$
  $m_\tau^2 = m_X^2 + 2(E_\tau - E_X)(E_X - |\vec{p}_X| cos\theta)$
  $m_\tau^2 \geq m_{\rm min}^2 = m_X^2 + 2(E_{\rm beam} - E_X)(E_X - |\vec{p}_X|)$.
- The empirical edge function:
  $f(m_{\rm min}) \sim (a_1 + a_2 m_{\rm min}) \tan^{-1}(m_{\rm min} - a_3)/a_4 + a_5 + a_6 m_{\rm min}$
  a_3 is a τ mass estimator

m_τ at Belle: Data



$$m_\tau = (1776.61 \pm 0.13) \text{ MeV}$$

m_τ at Belle: Monte Carlo



$$\Delta m_\tau = (1.16 \pm 0.14)\ \mathrm{MeV}$$

m_τ at Belle: Systematic Uncertainties – I

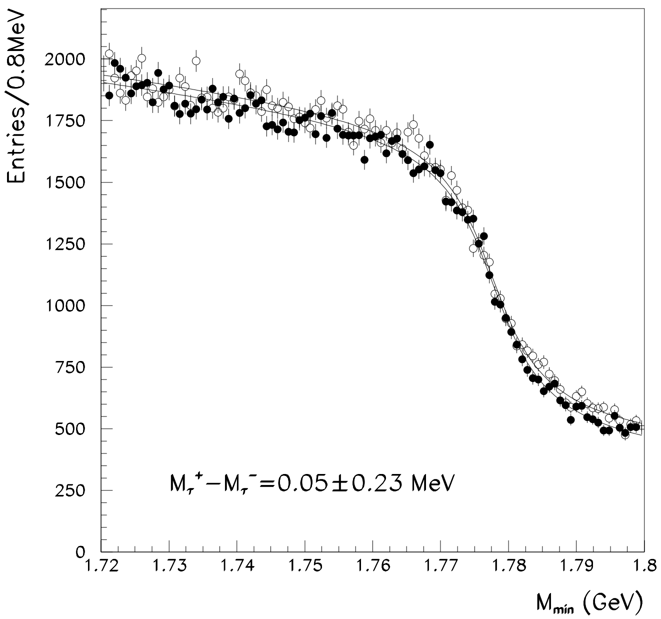
- $E_{\rm beam}$ is calibrated run by run using the beam-energy constrained mass of reconstructed B mesons. Its uncertainty of 1.5 MeV (Δm_B, tracking, $\Gamma_{\Upsilon(4S)}$) gives $\Delta m_\tau = 0.26$ MeV
- Momentum resolution (comparing MC and data on $e^+e^- \to \mu^+\mu^-$) – 0.02 MeV
- Choice of the edge parameterization gives 0.18 MeV:
  $f_1(m_{\rm min}) = (a_1 + a_2 m_{\rm min})\frac{m_{\rm min}-a_3}{\sqrt{a_2+(m_{\rm min}-a_1)^2}} + a_5 + a_6 m_{\rm min}$,
  $f_2(m_{\rm min}) = (a_1 + a_2 m_{\rm min})\frac{-1}{1+exp[(m_{\rm min}-a_3)/a_4]} + a_5 + a_6 m_{\rm min}$
- Variation of the fit range (1.72 – 1.80) GeV gives a shift of 0.04 MeV
- Variation of m_{a_1} and Γ_{a_1} in the ± 300 MeV range:
  model dependence of the 3π spectrum yields a shift < 0.02 MeV
- Backgrounds (misID τ decay, non-$\tau^+\tau^-$, ISR/FSR) $\Rightarrow$ a shift < 0.01 MeV
- A change of m_ν from 0 to 10 MeV gives a shift by -0.1 MeV

m_τ at Belle: Systematic Uncertainties – II

Source	σ, MeV/c^2
Beam energy and tracking	0.26
Edge parameterization	0.18
MC statistics	0.14
Fit range	0.04
Momentum resolution	0.02
Model of $\tau \to 3\pi\nu_\tau$	0.02
Background	0.01
Total	0.35

$$m_\tau = (1776.61 \pm 0.13 \pm 0.35)\ \text{MeV}$$

m_{τ^+} and m_{τ^-} at Belle



CPT test by m_{τ^+} vs. m_{τ^-}:

$\Delta m = m_{\tau^+} - m_{\tau^-} = 0.05 \pm 0.23 \pm 0.14$ MeV

Group	OPAL, 2000	Belle, 2006
$N_{\tau^+\tau^-}, 10^3$	160	370k
$\lvert\Delta m\rvert/m_\tau$	$< 3.0 \times 10^{-3}$	$< 2.8 \times 10^{-4}$

K. Belous et al., Phys. Rev. Lett. 99, 011801 (2007)

Progress of m_τ

Group	m_τ, MeV
BES, 1996	$1776.96^{+0.18+0.25}_{-0.21-0.17}$
PDG, 2006	$1776.99^{+0.29}_{-0.26}$
KEDR, 2006	$1776.81^{+0.25}_{-0.23} \pm 0.15$
Belle, 2006	$1776.61 \pm 0.13 \pm 0.35$
PDG, 2008	1776.84 ± 0.17

KEDR continues running to increase a data sample and decrease systematics

Belle has the best statistical error, but limited by systematic effects

m_τ at KEDR: 2008 preliminary

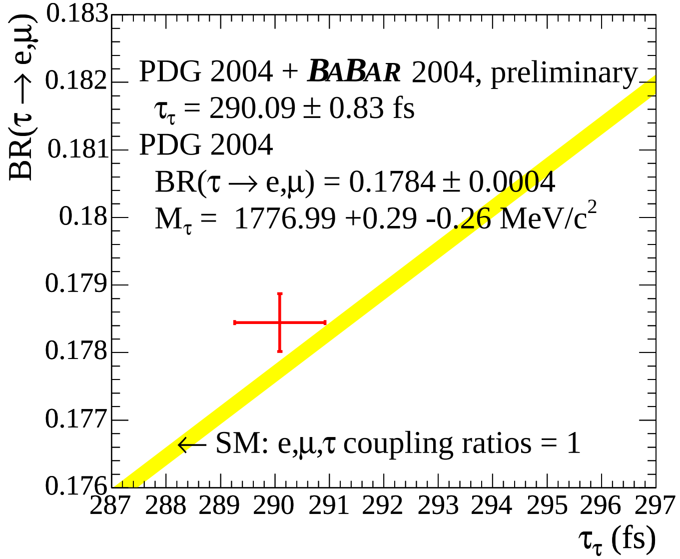
Year	2006	2008
$\int Ldt$, pb^{-1}	6.7	14.3
$N_{\rm ev}$ at thr.	11	26
m_τ, MeV	$1776.81^{+0.25}_{-0.23} \pm 0.15$	$1776.69^{+0.17}_{-0.19} \pm 0.15$

The goal is to reach a total error of 0.15 MeV

τ Lepton Lifetime

Source	$N_{\tau\tau}, 10^3$	τ_τ, fs	$\delta\tau_{\tau\,\mathrm{sys}}$, %
DELPHI, 2004	150	$290.9 \pm 1.4 \pm 1.0$	0.34
PDG, 2008	–	290.6 ± 1.0	0.28
BaBar, 2004	79000	$289.40 \pm 0.91 \pm 0.90$	0.31

- Measurement bias – 0.220%
- Background – 0.142%
- Alignment – 0.111%
- τ momentum – 0.100%
- Total – 0.310%



We can hopefully expect improvement in τ_τ from LHC

τ Leptonic Branching

Measurements of B_e, %

Source	$N_{\tau\tau}, 10^3$	$B, \%$	$\delta B_{sys}, \%$
ALEPH, 2005	56	$17.837 \pm 0.072 \pm 0.036$	0.2
CLEO, 1997	3250	$17.76 \pm 0.06 \pm 0.17$	1.0
PDG, 2008	–	17.85 ± 0.05	0.28

Systematic uncertainties in CLEO, %

N_{ev}	$N_{\tau\tau}$	ϵ	Trig.	PID	BG	Total
0.36	0.71	0.48	0.28	0.19	0.16	1.00

2008 Test of Lepton Universality

- After 23 years the MuLan group at PSI recently improved the μ^+ lifetime by a factor of 3.5 (D.B. Chitwood et al., Phys. Rev. Lett. 99, 032001 (2007)). The improved PDG-08 $\tau_\mu = (2.197019 \pm 0.000021)$ μs
- The unchanged PDG-08 $B_e = (17.85 \pm 0.05)\%$
- The unchanged PDG-08 $\tau_\tau = (290.6 \pm 1.0)$ fs
- The improved PDG-08 $m_\tau = (1776.84 \pm 0.17)$ MeV
- $r = 1.0030 \pm 0.0045$ $(0.67\sigma) \Rightarrow$ Leptonic universality is OK!

Do We Need a Higher m_τ Precision?

- We should know masses of fundamental particles with high precision

Particle	Mass, MeV	σ_m/m
e	$0.510998910 \pm 0.000000013$	$2.5 \cdot 10^{-8}$
μ	$105.6583668 \pm 0.0000038$	$3.6 \cdot 10^{-7}$
τ	1776.84 ± 0.17	$9.6 \cdot 10^{-5}$

- Is 1981 Koide formula pure numerology?

$$\frac{(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^2}{(m_e + m_\mu + m_\tau)} = 1.4999973^{+0.0000395}_{-0.0000304}$$

Lepton Universality in Hadronic Decays – I

$$\Gamma(\tau \to \pi\nu_\tau) = \frac{G_F^2 f_\pi^2 cos^2\theta_C}{16\pi} m_\tau^3 (1 - m_\pi^2/m_\tau^2)^2,$$

$$\Gamma(\pi \to \mu\nu_\mu) = \frac{G_F^2 f_\pi^2 cos^2\theta_C}{8\pi} m_\pi \; m_\mu^2 (1 - m_\mu^2/m_\pi^2)^2$$

$$\frac{\mathcal{B}(\tau \to \pi\nu_\tau)}{\mathcal{B}(\pi \to \mu\nu_\mu)} = \frac{m_\tau^3 (1 - m_\pi^2/m_\tau^2)^2}{2m_\pi \; m_\mu^2 (1 - m_\mu^2/m_\pi^2)^2} \frac{\tau_\tau}{\tau_\pi}$$

Lepton Universality in Hadronic Decays – II

For $\boldsymbol{\Gamma(\tau \to K\nu_\tau)}$ similarly, but $\boldsymbol{f_\pi \to f_{\rm K}}$ and $\boldsymbol{cos\theta_C \to sin\theta_C}$:

$$\frac{\mathcal{B}(\tau \to K\nu_\tau)}{\mathcal{B}(K \to \mu\nu_\mu)} = \frac{m_\tau^3(1 - m_{\rm K}^2/m_\tau^2)^2}{2m_{\rm K}\, m_\mu^2(1 - m_\mu^2/m_{\rm K}^2)^2}\frac{\tau_\tau}{\tau_{\rm K}}$$

Mode	$\mathcal{B}^{(\rm th)}$	$\mathcal{B}^{(\rm exp)}$
$\tau \to \pi\nu_\tau$	$(10.87 \pm 0.05)\%$	$(11.08 \pm 0.13)\%$
$\tau \to K\nu_\tau$	$(7.08 \pm 0.04) \cdot 10^{-3}$	$(7.1 \pm 0.5) \cdot 10^{-3}$

Charged Current Universality – I

A. Pich, April 2008:

$|G_\mu/G_e|$

$\mathcal{B}(\tau \to \mu)/\mathcal{B}(\tau \to e)$	1.0000 ± 0.0020
$\mathcal{B}(\pi \to \mu)/\mathcal{B}(\pi \to e)$	1.0021 ± 0.0016
$\mathcal{B}(K \to \mu)/\mathcal{B}(K \to e)$	1.004 ± 0.007
$\mathcal{B}(K \to \pi\mu)/\mathcal{B}(K \to \pi e)$	1.002 ± 0.002
$\mathcal{B}(W \to \mu)/\mathcal{B}(W \to e)$	0.997 ± 0.010

Charged Current Universality – II

$|G_\tau/G_e|$

$\mathcal{B}(\tau \to \mu)\tau_\mu/\tau_\tau$	1.0005 ± 0.0023
$\mathcal{B}(W \to \tau)/\mathcal{B}(W \to e)$	1.036 ± 0.014

$|G_\tau/G_\mu|$

$\mathcal{B}(\tau \to e)\tau_\mu/\tau_\tau$	1.0006 ± 0.0022
$\Gamma(\tau \to \pi)/\Gamma(\pi \to \mu)$	0.996 ± 0.005
$\Gamma(\tau \to K)/\Gamma(K \to \mu)$	0.979 ± 0.017
$\mathcal{B}(W \to \tau)/\mathcal{B}(W \to \mu)$	1.039 ± 0.013

Conclusions

- Better accuracy of m_τ after KEDR and Belle measurements
- $|G_\tau/G_\mu|$ improved
- Further progress impossible without improving τ_τ and $\mathcal{B}(\tau^- \to e^- \nu_\tau \bar{\nu}_e)$
- Universality of charged current checked using τ, π, K and W decays
  $\Gamma(W \to \tau)$ too big?
- Tests with τ are among the most precise, B factories help

Backup Slides

τ Lepton Factories

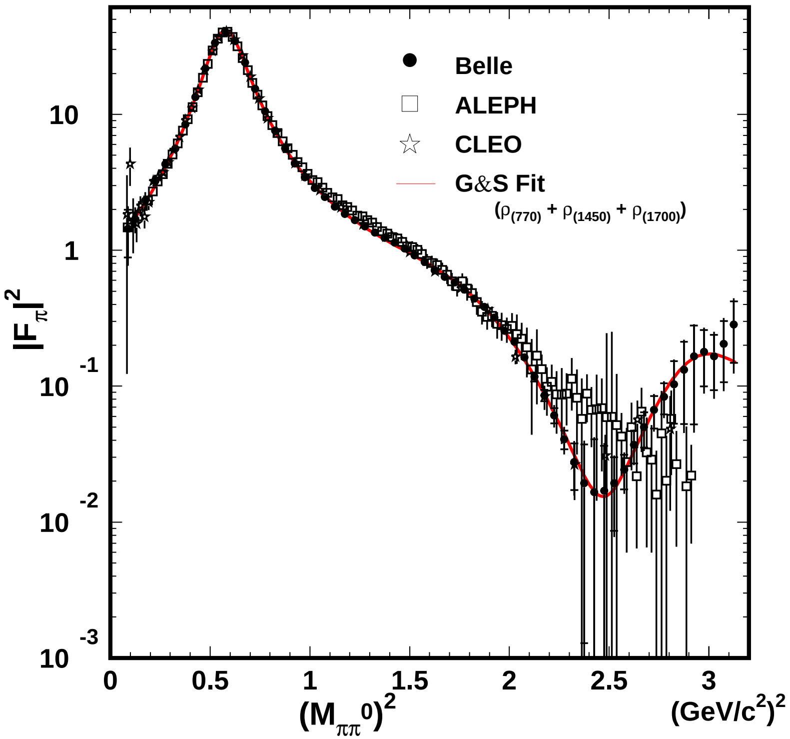
Group	$\int L\,dt$, fb^{-1}	$N_{\tau\tau}, 10^6$
LEP (Z-peak)	0.34	0.33
CLEO (10.6 GeV)	13.8	12.6
BaBar (10.6 GeV)	384	350
Belle (10.6 GeV)	543	490
τ-c (4.2 GeV)	10	32
SuperB	50k	45k

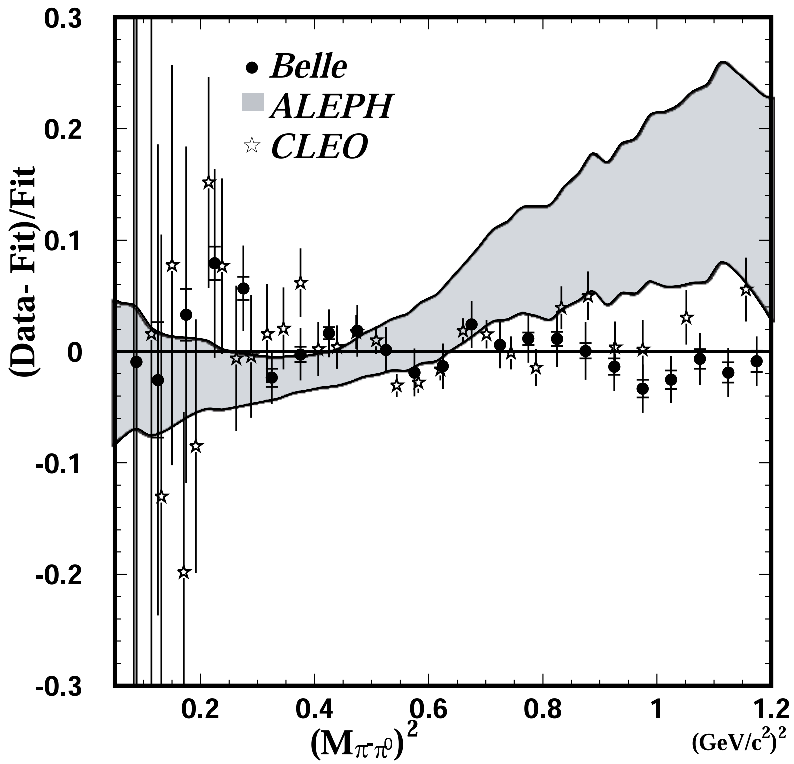
BaBar ($\sim$ 530 fb^{-1}) and Belle ($\sim$ 850 fb^{-1}) collected together about 1.4 ab^{-1}

B-factory is also a τ factory producing $0.9 \cdot 10^6$ $\tau^+\tau^-$ pairs per each fb^{-1}!!

New data on $\tau^- \to \pi^-\pi^0\nu_\tau$ from Belle

From 64M $\tau^+\tau^-$ pairs Belle selects 5.5M $\tau^- \to h^-\pi^0\nu_\tau$ events!

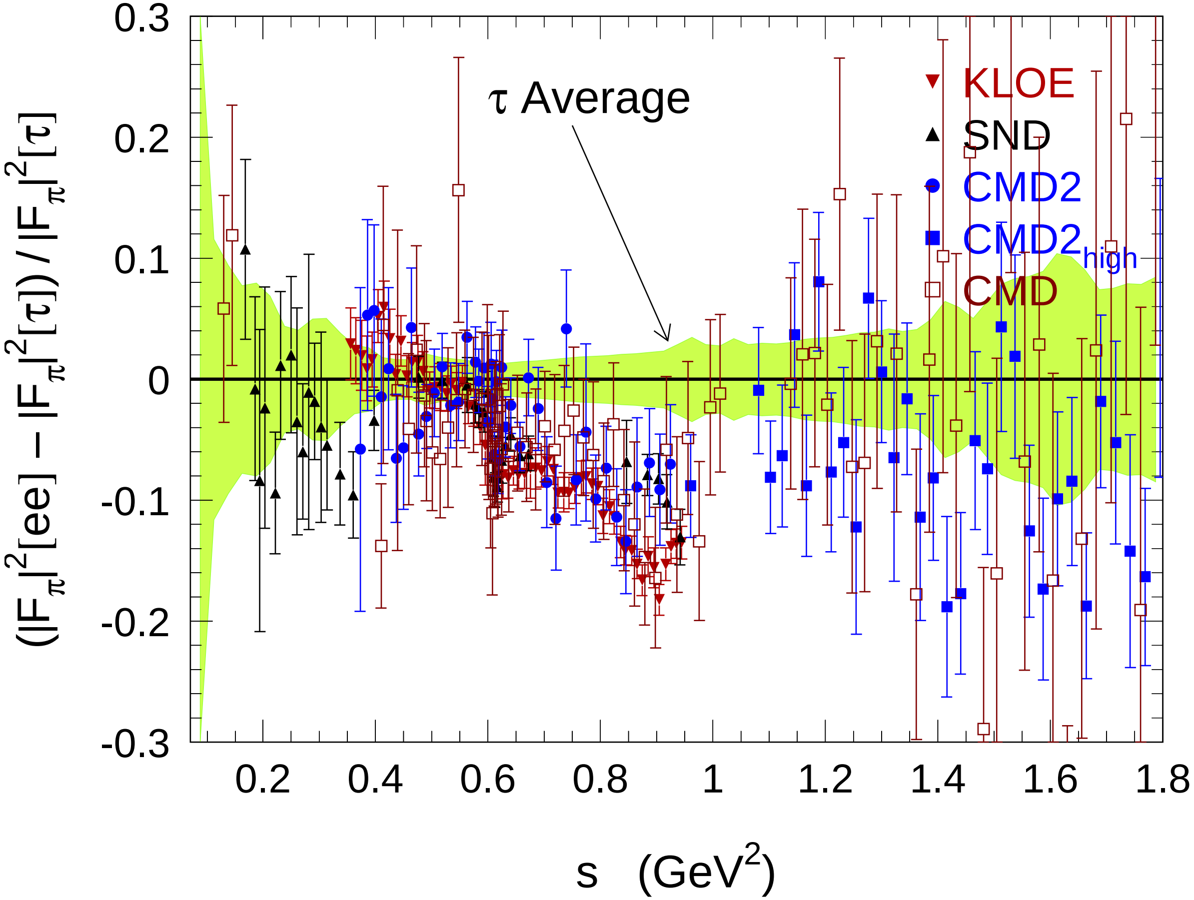




$\mathcal{B}_{\rm Belle} = (25.15 \pm 0.04 \pm 0.40)\%$ $\mathcal{B}_{\rm ALEPH} = (25.471 \pm 0.097 \pm 0.085)\%$

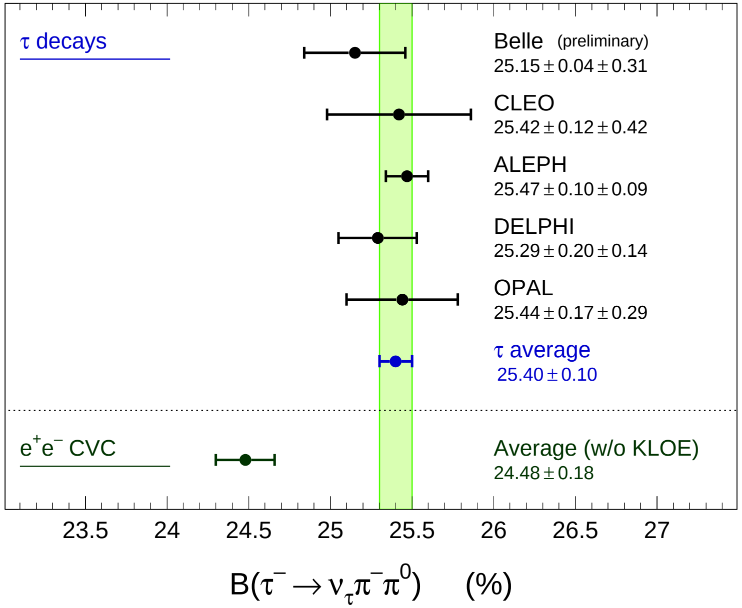
The contributions to $a_\mu^{\rm had}$ are also compatible due to compensation at tails

CVC in the 2π Channel. e^+e^- vs. τ (Spectra)



Above the ρ meson e^+e^- spectral functions are lower than in τ decays

CVC in the 2π Channel. e^+e^- vs. τ (Branchings)



The branching from all groups is systematically higher than the CVC prediction: $\mathcal{B}_\tau - \mathcal{B}_{ee} = (0.92 \pm 0.21)\%$ or 4.5σ from 0. The discrepancy is a 3.6% effect, about twice the SU(2) correction. The puzzle remains unsolved $\Rightarrow$ τ data not used

M. Benayoun, arXiv:0711.4482: no conflict with consistent SU(2) breaking

Theory vs Experiment – I

Contribution	$a_\mu, 10^{-10}$
Experiment	11659208.0 ± 6.3
QED	11658471.8 ± 0.016
Electroweak	$15.4 \pm 0.1 \pm 0.2$
Hadronic	693.1 ± 5.6
Theory	11659180.3 ± 5.6
Exp.–Theory	$27.7 \pm 8.4\ (3.3\sigma)$

The difference between experiment and theory is 3.3σ!

(K.Hagiwara et al., PLB 649,173(2007)) claim even 3.4σ

while F.Jegerlehner,2008 – 2.8σ)

Theory vs Experiment – II