Tau mass measurement at KEDR

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Outline: tau mass measurement at KEDR

- Resonant depolarization method: BINP 1975

  masses of $K^{\pm}, K^{\circ}, \omega, \varphi, J/\psi, \psi', \Upsilon, \Upsilon', \Upsilon''$

$$\frac{\triangle m}{m} = 10^{-4} \div 4\cdot 10^{-6}$$

- VEPP-2(M), VEPP-4(M), DORIS-II, CESR, LEP
  SR–machines BESSY-II, SLS, ALS

- High precision measurement of τ mass
  - metrological issue
  - lepton universality test

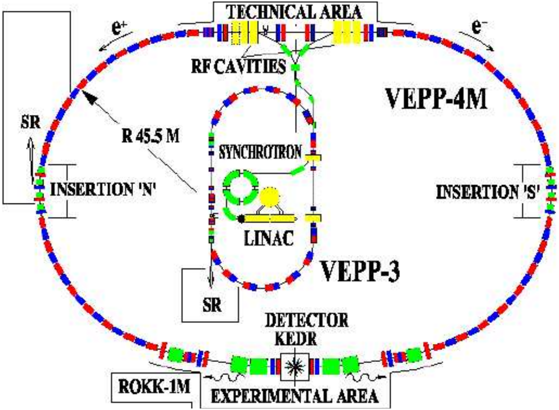
- PDG-2006

$$M_{\tau} = 1776.99^{+0.29}_{-0.26} \text{ MeV}$$

  dominated by BES(1996)

VEPP–4M complex

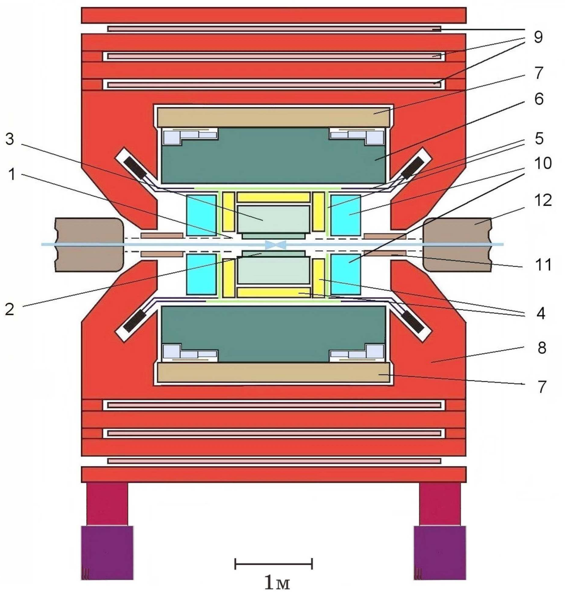
OLYA(1980): $J/\psi,\psi'$ MD-1(1982-1985): $\Upsilon,\Upsilon',\Upsilon'',R$ KEDR(2002...): $J/\psi,\psi',\psi'',\tau$



Circumference	366 m
Magnetic radius	34.5 m
Beam energy	$1 \div 6$ GeV
Momentum compaction	0.017
Number of bunches	2×2
Vertical beta-function	5 cm
Luminosity, $\mathrm{E}=1.5$ GeV	2×10^{30}
Beam current, $\mathrm{E}=1.5$ GeV	2 mA
Luminosity, $\mathrm{E}=5.0$ GeV	2×10^{31}
Beam current, $\mathrm{E}=5.0$ GeV	10 mA
RF frequency	181.8 MHz
Revolution period	1.2 μs

ROKK-1M – Compton backscattering facility

KEDR detector

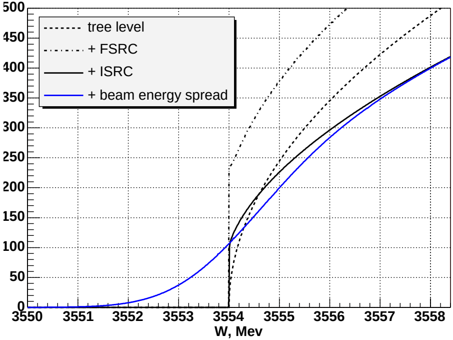


1. Vacuum chamber
2. Vertex detector
3. Drift chamber
4. Threshold aerogel counters
5. ToF–counters
6. Liquid krypton calorimeter
7. Superconducting coil (0.65 T)
8. Magnet yoke
9. Muon tubes
10. CsI-calorimeter
11. Compensation solenoid
12. VEPP–4M quadrupole

Scattered electron tagging system for $\gamma\gamma$-physics is not shown

General experimental scenario

- Measurement of the threshold behavior of the cross section is the most direct method of τ mass determination: DELCO(1978), BES(1992)



Narrow region $|E_{beam} - m_\tau| \sim \sigma_E$ is most sensitive to the mass value $\Rightarrow$ high requirements on E_{beam}, σ_E accuracy and stability

- Reasonably optimal luminosity distribution for the 3–parameter problem:
  - $\approx$15% below the threshold (*background*)
  - $\approx$70% $\pm$ 0.5 MeV around the threshold (*mass*)
  - $\approx$15% well above the threshold (*detection efficiency*)
- Threshold search: $E_{beam} = m_\tau$-0.5, m_τ, m_τ+0.5, m_τ+1 or m_τ–1 MeV

Resonant Depolarization Method

- Radiative polarization of electron beams (Sokolov–Ternov, 1964)

$$\frac{1}{\tau_{pol}} \approx \frac{5\sqrt{3}}{8} \cdot \frac{\lambda_e r_e c}{R^3}\gamma^5$$

- Spin precession around the guiding field with the frequency of

$$\Omega_S = \omega_0 \left(1 + \gamma \frac{\mu'}{\mu_0}\right)$$

ω_0 – beam revolution frequency
μ_0, μ' – normal and anomalous parts of the electron magnetic moment

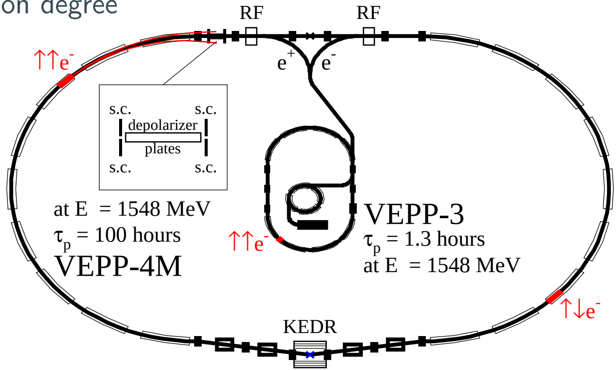
- Beam polarization can be destroyed by an external EM-field of the frequency Ω_{dep} satisfying the resonant condition

$$\Omega_S \pm \Omega_{dep} = \omega_0 n$$

- Ω_S is measured in the moment of the polarization destruction during the depolarizer frequency scan

VEPP-4M polarimeter

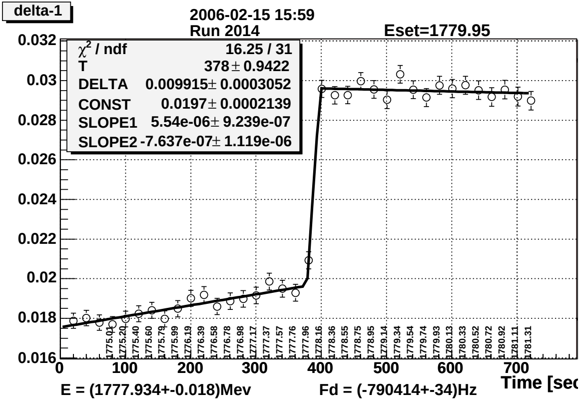
- At VEPP-4M the depolarization is detected by the change of the intrabeam scattering (Touschek effect) rate depending on the polarization degree



- Comparison of intrabeam scattering rates from the two electron bunches (polarized ↑↑ and unpolarized ↑↓)

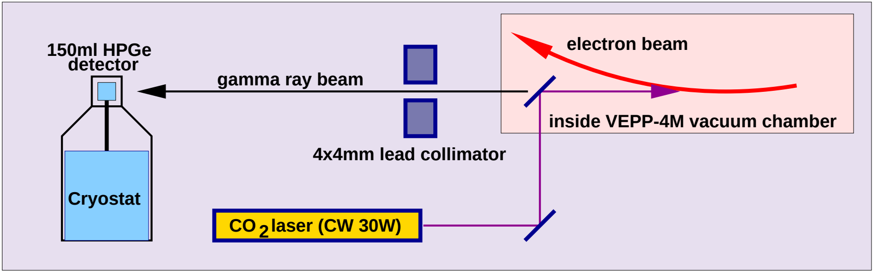
$$\triangle = (f_{pol} - f_{unpol})/f_{pol}$$

- Typical energy calibration run:



- Complete procedure takes $\simeq$ 2 hours at the τ threshold
- Energy measurement accuracy 2÷20 keV depending on $d\Omega_{dep}/dt$
  - VEPP-4M polarization life time $\simeq$25 mins at $E = 1777$ MeV
  - No polarization at VEPP-3 at $E = 1700 \div 1830$ MeV
  - Special machine operation scenario at the τ threshold

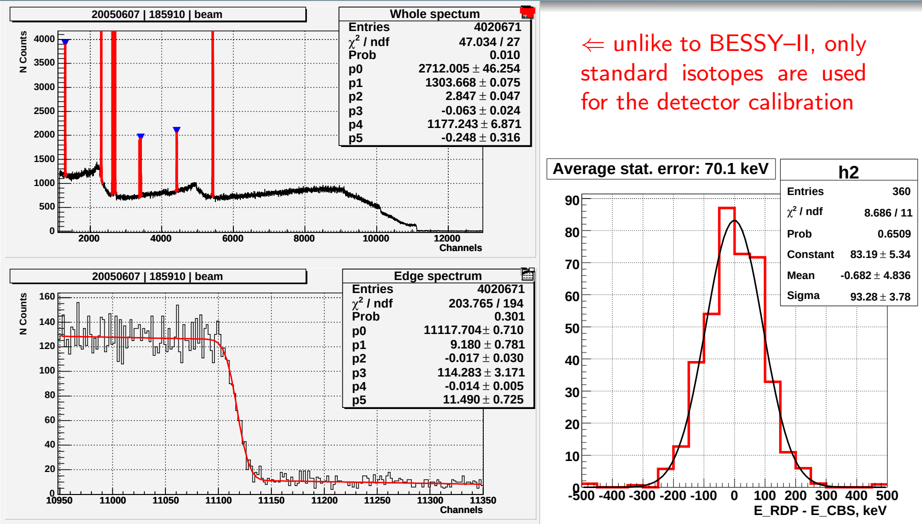
- R. Klein et al., NIM A384 (1997) 293: BESSY–I, 800 MeV
- R. Klein et al., NIM A486 (2002) 545: BESSY–II, 1700 MeV



$$\omega'_{max} = \frac{E^2}{E + m^2/4\omega_{laser}}$$

- CO_2 – laser ($\lambda = 10.591\ \mu$m, $\omega_{laser} = 0.12$ eV, $\omega'_{max} \simeq 6$ MeV)

Compton backscattering spectrum

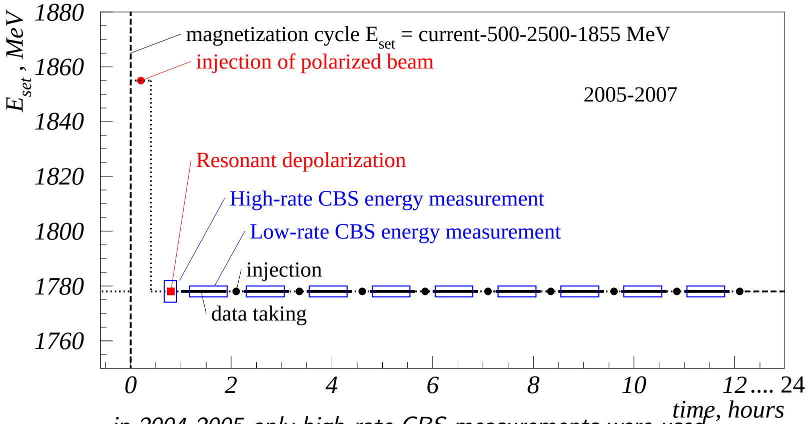


⇐ unlike to BESSY–II, only standard isotopes are used for the detector calibration

- Final CBS calibration with resonant depolarization ⇑
- Energy determination accuracy: 50÷100 keV (stat), 60 keV (syst)
- Energy spread determination accuracy ≃ 7 % (syst)

VEPP-4M operation scenario

- Data taking cycle at given energy point ($\simeq$ 24 hours):

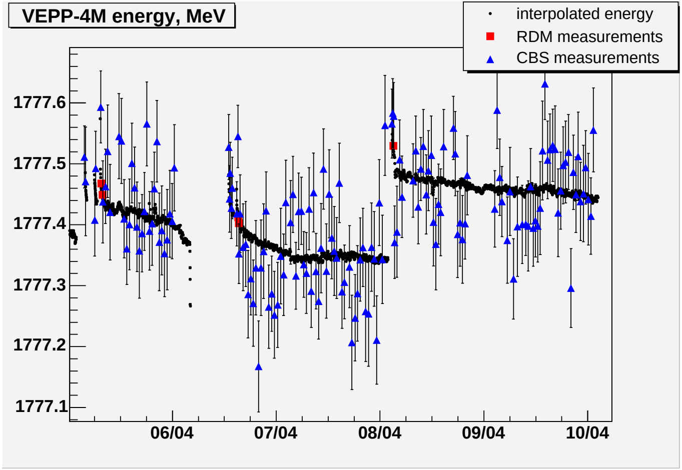


in 2004-2005 only high-rate CBS measurements were used, incompatible with data taking

- RDM-energy is interpolated between calibrations using machine field and temperature measurements with $\simeq$ 30 keV accuracy

Example of VEPP-4M energy behavior

- April 2006:



- Energy drop of about 0.1 MeV in 1.5 hours after the magnetization cycle (no data taking at that time, resonant depolarization delay of 1 hour)

- Compton backscattering accuracy on σ_E seems insufficient
- VEPP-4M settings related to σ_E
  - optimized for m_τ measurements
  - kept unchanged since 2004
- 2004-2006: 3 scan of ψ'

$$\sigma_W = 1.08 \pm 0.02 \pm 0.02 \ \text{MeV}$$

- 2005: scan of J/ψ, $\int Ldt = 230$ nb^{-1}

$$M^{2005}_{J/\psi} - M^{2002}_{J/\psi} = 7 \pm 10 \pm 17 \ \text{keV}$$

$$\sigma_W = 0.70 \pm 0.01 \ \text{MeV}$$

- 9% deviation from the expected dependence $\sigma_W(E) \propto E^2$
  - the same in J/ψ–, ψ'–mass experiment (2002)
- *assuming linear growth of the deviation with $E - M_{\psi'}/2$:*

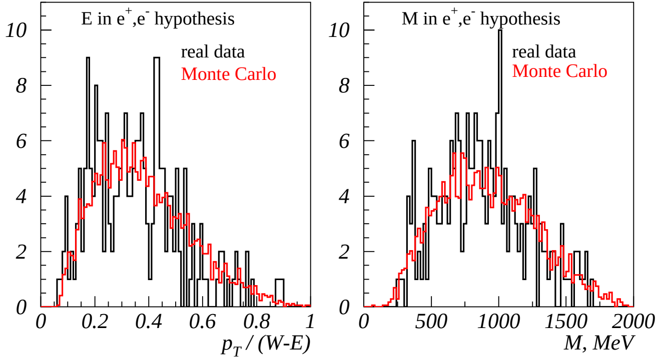
$$\sigma_W(m_\tau) = 1.00 \pm 0.02 \pm 0.03 \ \text{MeV}$$

Tau event selection

- Event selection: 2–prong events, $|\cos\phi| < 0.93$, $0\div3$ photons

$$e^+e^- \to (\tau \to e\nu_\tau\bar{\nu}_e), (\tau \to e\nu_\tau\bar{\nu}_e,\ \mu\nu_\tau\bar{\nu}_\mu, \pi\nu_\tau, K\nu_\tau, \rho\nu_\tau)^* + \mathrm{c.c}$$

$\mu/\pi/K$ identification is not used, no extra photons with $E_\gamma > 30$ MeV
$E < 2200$ MeV, $p_T > 200$, $p_T/(W-E) > 0.06$

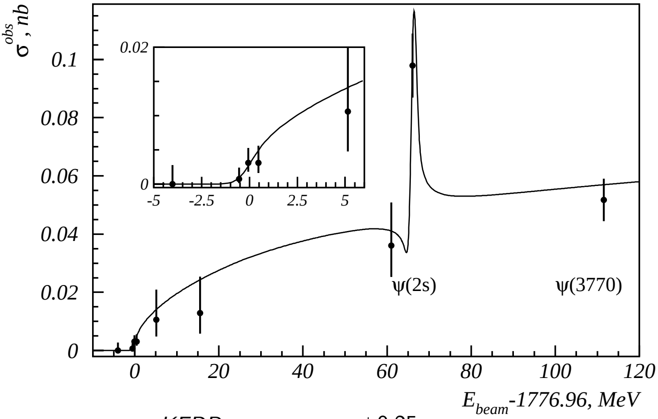


- Detection efficiency $\varepsilon \approx 0.025$, 10% reduction for $W = 2M_\tau \to M_{\psi''}$
- No distortion of the residual background W dependence due to cuts

Published result on partial statistics

- 6.7 pb^{-1}, 11 events at the threshold /JETP Lett. 85(2007)347/
- 4-parameter data fit:

$$\sigma_B = 0^{+0.58}\ \text{pb},\ \varepsilon = 2.25 \pm 0.28\ \%,\ \Gamma_{ee}^{\psi'} \cdot B^{\psi' \to \tau\tau} = 8.0 \pm 2.2\ \text{eV}$$



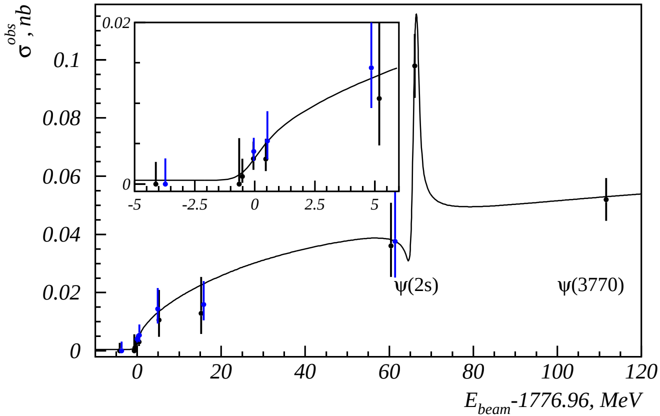
$$M_\tau^{KEDR} = 1776.81^{+0.25}_{-0.23} \pm 0.15\ \text{MeV}$$

$$M_\tau^{KEDR} - M_\tau^{PDG} = -0.18^{+0.25}_{-0.23} \pm 0.15\ \left(^{+0.29}_{-0.26}\ PDG\right)\ \text{MeV}$$

Preliminary result on full statistics

- 14.3 pb^{-1}, 26 events at the threshold
- 5-parameter data fit:

$$\sigma_B = 0^{+0.32}\text{ pb},\ \varepsilon = 2.07 \pm 0.25\ \%,\ \varepsilon' = 1.49 \pm 0.25\ \%$$



$$M_\tau^{KEDR} = 1776.69^{+0.17}_{-0.19} \pm 0.15\text{ MeV}$$

Systematic uncertainties

- Conservative estimates

Beam energy determination	: 35 keV
Detection efficiency variations	: 120 keV
Energy spread determination accuracy	: 20 keV
Background dependence on the beam energy	: 20 keV
Luminosity measurement instability	: 80 keV
Beam energy spread variation	: 10 keV
Cross section calculation (r.c., ψ' interference)	: 30 keV
Sum in quadrature	: 150 keV

Conclusion

- KEDR preliminary result on τ–mass

$$M_\tau = 1776.69^{-0.19}_{+0.17} \pm 0.15 \text{ MeV}$$

agrees with PDG-2006 value

$$M_\tau = 1776.99^{+0.29}_{-0.26} \text{ MeV}$$

the recent results of BELLE and BABAR*(this workshop)*

$$M_\tau = 1776.61 \pm 0.13 \pm 0.35 \text{ MeV},$$

$$M_\tau = 1776.68 \pm 0.12 \pm 0.39 \text{ MeV}$$

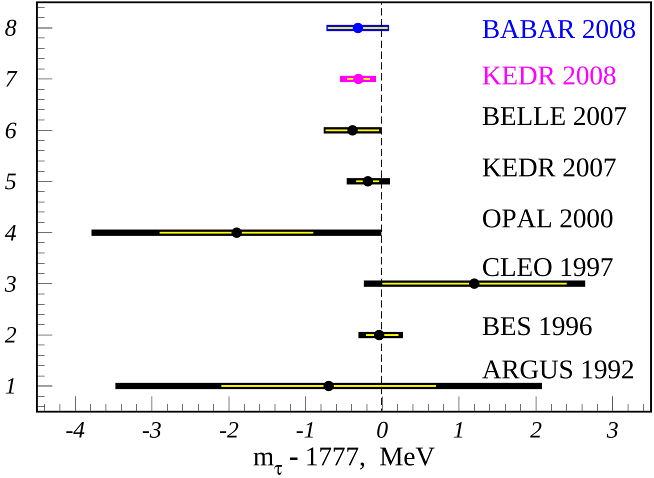
and has better accuracy

- We plan to achieve the accuracy of $0.15 \div 0.18$ MeV on completion of the data analysis

- Collaboration BES–BINP for τ–mass measurement at BEPC

Conclusion

Summary of τ-mass results: 1776.76 ± 0.15 MeV



Total (black) and systematic (yellow) errors are shown
Dashed line shows the world average-2006

The result DELCO 1978 $m_\tau = 1783^{+3}_{-4}$ MeV is not drawn

Backup: progress in $\mu\tau$-universality test

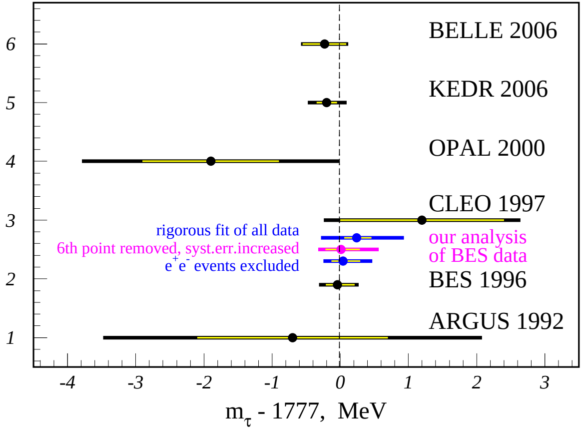
$$r = \frac{G_F^2(\tau)}{G_F^2(\mu)} \propto \frac{B(\tau \to \nu_\tau e \bar{\nu}_e)}{\tau_\tau m_\tau^5}$$

r	t_τ, fs	$B_{\tau\to\nu_\tau e\bar{\nu}_e}$, %	m_τ, MeV	Comments
0.9405	305.6 ± 6.0 ± 0.0185	17.93 ± 0.26 ± 0.0136	$1784.1\ ^{+2.7}_{-3.6}$ $^{+0.0095}_{-0.0071}$	PDG 1992 –2.4σ
0.9609	295.7 ± 3.2 ± 0.0104	17.76 ± 0.15 ± 0.0081	$1784.1\ ^{+2.7}_{-3.6}$ $^{+0.0097}_{-0.0073}$	W.A., October 1992 –2.4σ
0.9800	± 0.0106	± 0.0083	1777.1 ± 0.5 ± 0.0012	with BES preliminary –1.5σ
0.9999	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	290.6 ± 1.1 ± 0.0038	17.84 ± 0.06 ± 0.0034	$1776.99\ ^{+0.29}_{-0.26}$ ± 0.0008	PDG 2002-2006 +0.4σ

($\pm$ *contribution in uncertainty of* r)

Backup: on accuracy of BES result

- questions to BES τ-mass analysis were discussed at Tau'04 and around
  A.G. Shamov, Nucl.Phys. B(Proc. Suppl.) 144 (2005) 113
  BES comment on that: *ibidem, page 120*



Backup: more on accuracy of BES result

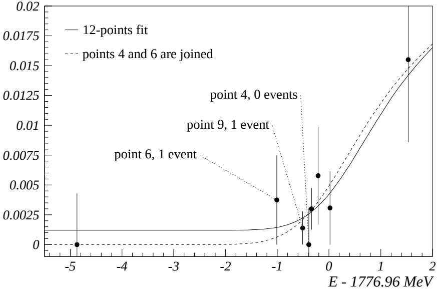
- Main point of BES comment:

  τ-mass accuracy is higher than expected, because of the additional background data not mentioned in the publication:

  $$N_{\tau\tau} = 37 \text{ at } 5\cdot 10^6 \ J/\psi \text{ events}$$

- Comment on BES comment:

  Data collected at J/ψ yields in the very low estimate of the single-photon $q\bar{q}$-background, but says nothing about dominating two-photon background: $5\cdot 10^6$ J/ψ's corresponds to $\simeq 2\text{pb}^{-1}$, thus $\sigma_{bg,\gamma\gamma} \leq 17.5$ pb. The rigorous fit of BES data gives $\sigma_{bg} \approx 1$ pb:



The points 4 and 6 were joined in the single term of the likelihood function of BES