τ threshold experiments: status and expectations

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1. Introduction
   - *Is a new experiment desirable?*
2. Discussion of BES m_τ result
   - *Is the error evaluation procedure fully correct?*
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   - *Beam energy determination*
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Introduction

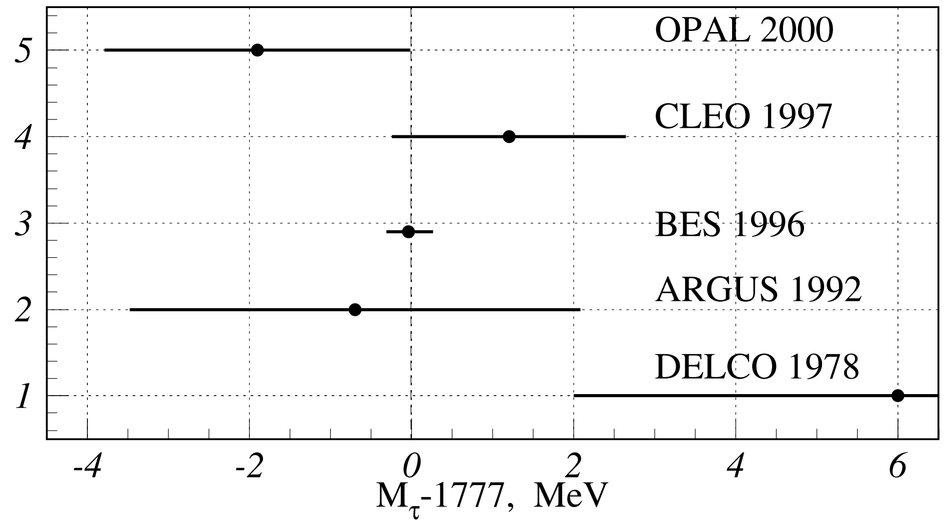
Measurement of the threshold behavior of the production cross section is the most direct method of τ mass determination.

- Mass is a fundamental characteristic of a particle interesting by itself.
- In case of τ-lepton measurement of the mass m_τ, the life time t_τ and the $B(\tau \to \nu_\tau e \bar{\nu}_e)$ provides the $\mu\tau$-universality check:

$$G_F^2 \propto \frac{B(\tau \to \nu_\tau e \bar{\nu}_e)}{t_\tau m_\tau^5}, \qquad \frac{\delta G_F^2}{G_F^2} = 5 \times \frac{\delta m_\tau}{m_\tau}.$$

Current status of τ mass measurements (PDG-2004):

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$1776.99^{+0.29}_{-0.26}$ OUR AVERAGE					
$1775.1 \pm 1.6 \pm 1.0$	13.3k	[1] ABBIENDI	00A	OPAL	1990–1995 LEP runs
$1778.2 \pm 0.8 \pm 1.2$		ANASTASSOV	97	CLEO	$E^{ee}_{cm} = 10.6$ GeV
$1776.96^{+0.18}_{-0.21}{}^{+0.25}_{-0.17}$	65	[2] BAI	96	BES	$E^{ee}_{cm} = 3.54$–3.57 GeV
$1776.3 \pm 2.4 \pm 1.4$	11k	[3] ALBRECHT	92M	ARG	$E^{ee}_{cm} = 9.4$–10.6 GeV
$1783\ ^{+3}_{-4}$	692	[4] BACINO	78B	DLCO	$E^{ee}_{cm} = 3.1$–7.4 GeV



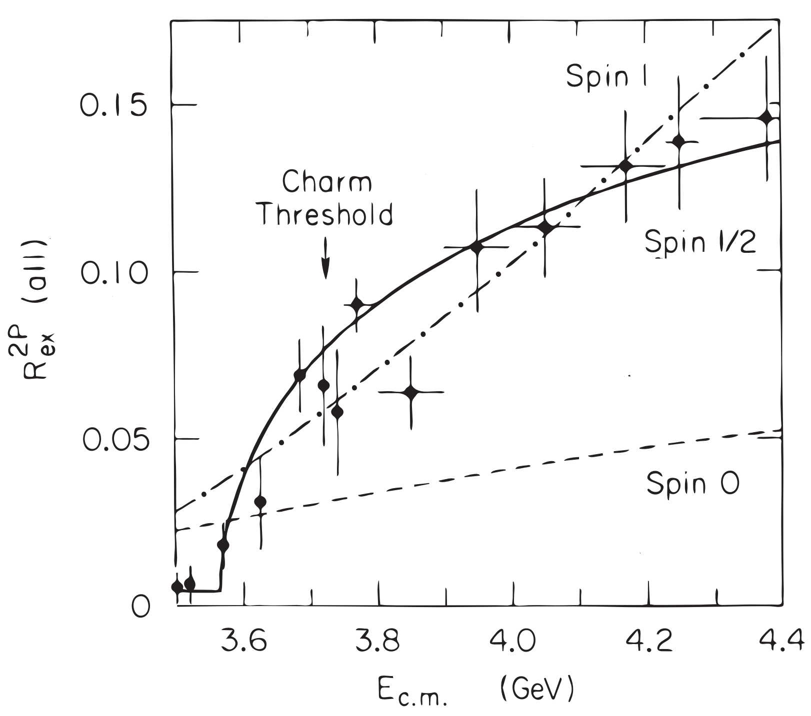
The world average is dominated by the BES results

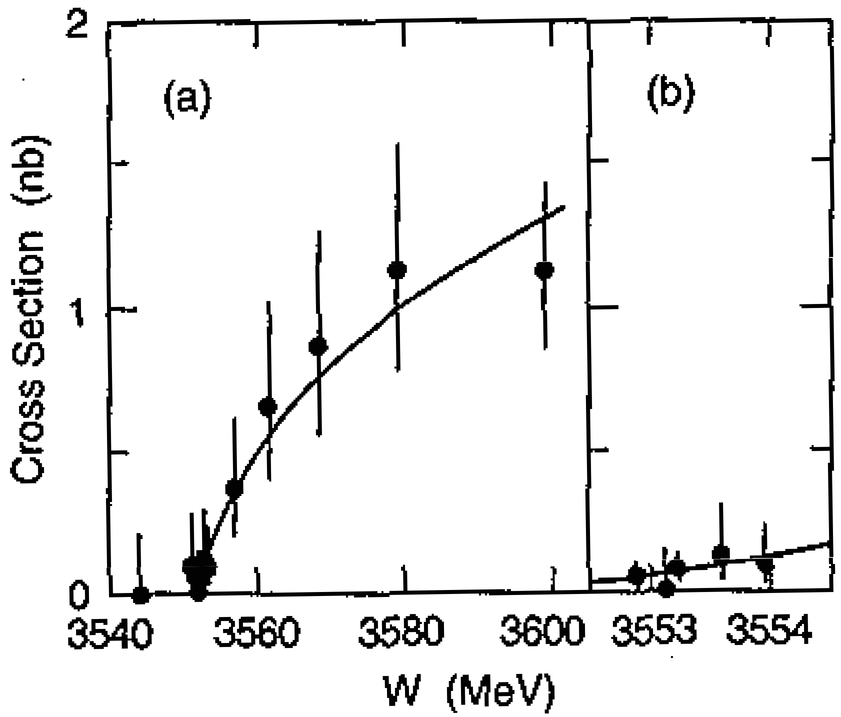
Progress in $\mu\tau$-universality check:

$\frac{G_F^2(\tau)}{G_F^2(\mu)}$	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 ± 0.012	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, 2004 +0.4σ

Accuracy $\delta m_\tau \approx 0.3$ MeV seems sufficient

DELCO-1978, $\delta M = ^{+3}_{-4}$ MeV: BES-1996, $\delta M = ^{+0.31}_{-0.27}$ MeV:





692 events 65 events

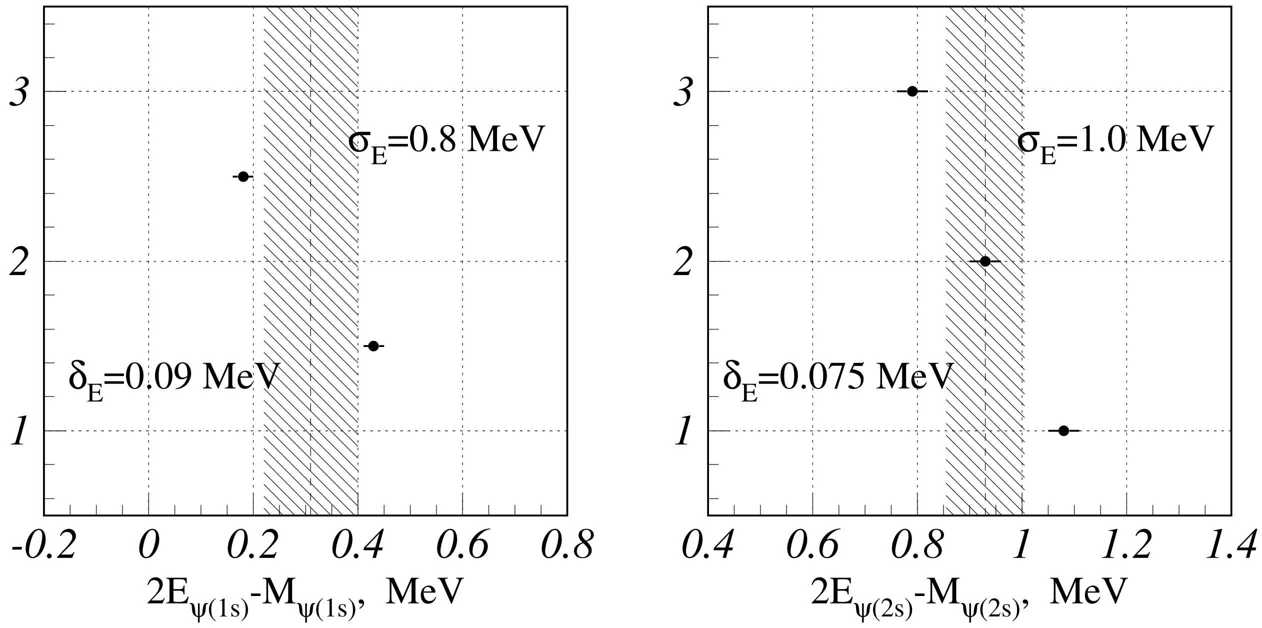
Narrow region $|E_{beam} - m_\tau| \sim \sigma_E \sim 1$ MeV
is most sensitive to the mass value $\Rightarrow\Rightarrow$
high accuracy of E_{beam} and σ_E determination is required

Natural accuracy of E_{beam} determination $\sim 5{\cdot}10^{-4}$
for all accelerators:

- DELCO – shift by $M_{\psi'}/2 - E_{beam}(\psi') \approx 1$ MeV
- BES – linear energy scale correction using M_{ψ} and $M_{\psi'}$:

$$M_{\psi} = 3096.03 \pm 0.09, \;\; M_{\psi'} = 3686.00 \pm 0.10 \quad \text{(OLYA/VEPP-4, 1980)}$$

BES, 2 scans of ψ and 3 scans of ψ':



δ_E – reproducibility of the BEPC energy setting

Accelerator related uncertainty of BES m_τ:

Source	Uncertainty, MeV
Uncertainty in the cm. energy scale	± 0.09
Uncertainty in the cm. energy spread	± 0.02
Bias in the scanning procedure	± 0.10
Total	± 0.14

1. Is the nonlinearity of BEPC energy setting small enough?
   - Is not discussed in the BES publications
   - For VEPP-4 $\delta m_\tau \sim 1$ MeV (*BEPC situation seems better*)
2. Can data points energy uncertainty be estimated accurately using δ_E values for ψ scans?
3. Are energy uncertainty of distinct data points uncorrelated?
   - It seems there are no clear answers

In the case when
world average is dominated by the single experiment
complicated in the accelerator and detector related aspects
the additional experiment is desirable
to confirm the accuracy achieved.

Planning experiment with KEDR detector at VEPP-4M collider:

- Absolute energy calibration with accuracy ≈ 0.01 MeV
- Frequent energy monitoring with accuracy ≈ 0.1 MeV
- Smaller beam energy spread
- Higher efficiency of $\tau^+\tau^-$ selection

Discussion of BES m_τ result

1. Accelerator related questions
   - *Are not described in details in the BES publications*
2. $\tau^+\tau^-$ event selection
   - *Perfectly described, no questions*
3. Statistical analysis
   - Nonstandard error evaluation procedure

     ♠ *Correlation of parameters of the fit?*
   - Very small statistics ($0 \div 3$ events in the most valuable data points)

     ♠ *Maximum likelihood method is* **asymptotically unbiased**...

Raw numbers of the BES τ threshold experiment:

Point	$W/2$ (MeV)	σ_W (MeV)	$\mathcal{L}$ (nb^{-1})	N (events)	R_ϵ
1	1784.19	1.34	245.8	9	1.0
2	1780.99	1.33	248.9	7	1.0
3	1772.09	1.36	232.8	0	0.9
4	1776.57	1.37	323.0	0	0.9
5	1778.49	1.44	322.5	5	1.0
6	1775.95	1.43	296.9	1	0.9
7	1776.75	1.47	384.0	2	0.9
8	1776.98	1.47	360.8	1	0.9
9	1776.45	1.44	794.1	1	0.9
10	1776.62	1.40	1109.1	3	0.9
11	1799.51	1.44	499.7	24	1.0
12	1789.55	1.43	250.0	12	1.0

J.Z. Bai *et al.*, Phys. Rev. D53 (1996) 20.

Section VIII:

"... The mass of the τ lepton is obtained from the final $\tau^+\tau^-$ candidate sample by means of a maximum likelihood fit to the cm. energy dependence of the τ pair production cross section. The likelihood function is product of Poisson distributions, *one at each of the 12 scan points*..."

"... The fit to the data of Table V is performed using the program MINUIT, and the *maximum likelihood solution* is found to correspond to the parameter values

$$
\begin{aligned}
m_\tau &= 1776.97^{+0.18}_{-0.21}\ \mathrm{MeV},\\
\epsilon &= 4.26^{+0.55}_{-0.51}\ \%,\\
\sigma_B &= 0^{+0.74}\ \mathrm{pb}.
\end{aligned}
$$

For ϵ and σ_B, the quoted uncertainties are obtained *by fixing the other two parameters* at their maximum likelihood values and finding the parameter values corresponding to a decrease in $\ln L$ of 0.5.

The *statistical* uncertainty in m_τ is found *by setting* $\epsilon = 4.26\%$ and $\sigma_B = 0$, and integrating the likelihood function to find the 68.27% confidence level interval ...

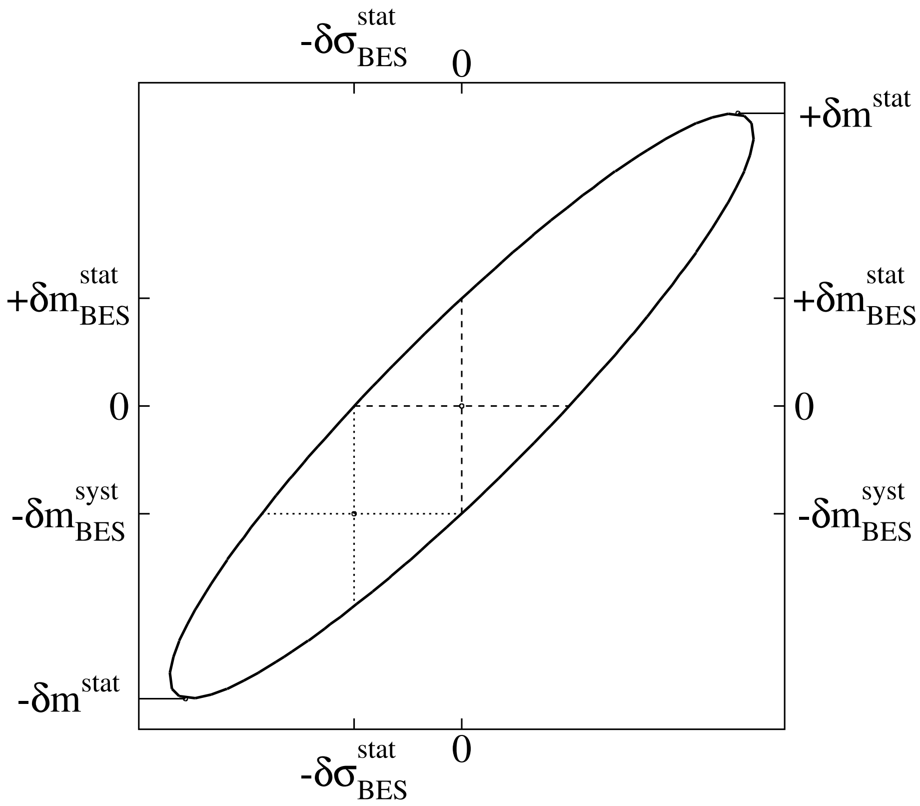
For a Gaussian likelihood function, these error estimates would be the same as those obtained from a decrease in $\ln L$ of 0.5 ... a decrease in $\ln L$ of 0.5 yields error estimates of $^{+0.196}_{-0.201}$ MeV, so that in this instance there is very little difference in the results of the two methods."

Section IX:

"...The *systematic* uncertainties associated with the fitted efficiency parameter are obtained by setting ϵ at its $\pm 1\sigma$ values and maximizing the likelihood with respect to m_τ with $\sigma_B = 0$. This yields changes in the fitted mass of $\Delta m = {}^{+0.09}_{-0.10}$ MeV.

In a similar way, the uncertainty in m_τ associated with $\delta\sigma_B = +0.74$ pb (corresponding to a 1σ background level of 3.8 events) is found ... this yields a systematic error contribution $\Delta m = +0.19$ MeV."

Standard procedure of error evaluation vs that of BES:



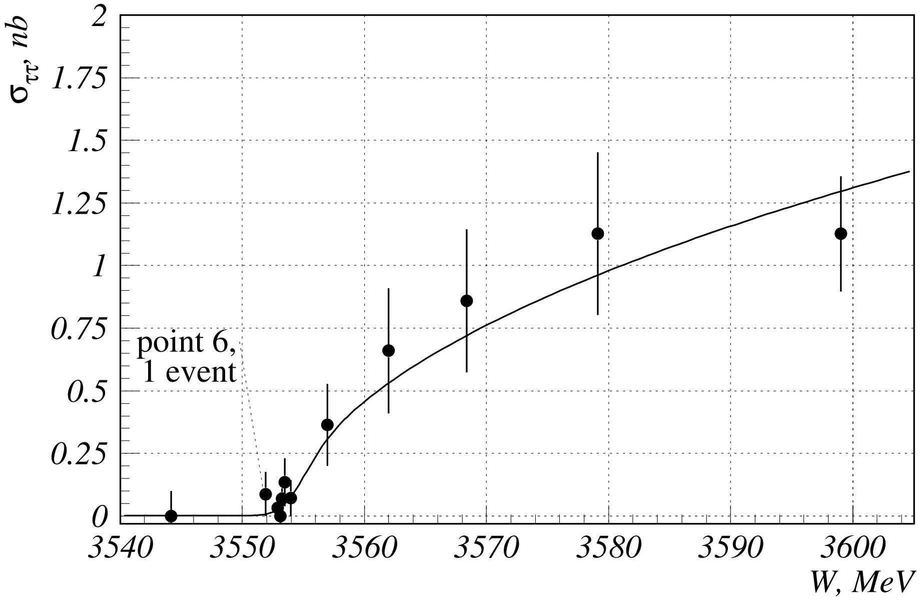
- Even linear sum of $\delta M_{BES}^{stat} + \delta M_{BES}^{syst}$ can be $< \delta M^{stat}$, in the total error they are summed up in quadrature
- Actual systematic error due to σ_B, ϵ dependence on W is ignored (*event selection criteria applied are energy dependent*)

$\hookrightarrow$ uncertainty of the BES τ mass value is underestimated $\hookleftarrow$

Our fits of the published BES data:

by	m_τ, MeV	ϵ, %	σ_B, pb
A.G. Shamov:	$1777.238^{+0.66}_{-0.49}$	$4.243^{+0.637}_{-0.588}$	$1.164^{+1.639}_{-1.164}$
A.D. Bukin:	$1777.240^{+0.66}_{-0.49}$	$4.144^{+0.600}_{-0.558}$	$1.033^{+1.460}_{-1.032}$
I.B. Nikolaev:	$1777.235^{+0.66}_{-0.48}$	$4.191^{+0.628}_{-0.572}$	$1.028^{+1.462}_{-1.028}$

(*some difference in radiative correction treatment*)



Nonzero background is due to the single event in 6th data point at $W = 3551.9$ MeV.

With 6th point excluded

$$\sigma_B = 0^{+1.23}$$

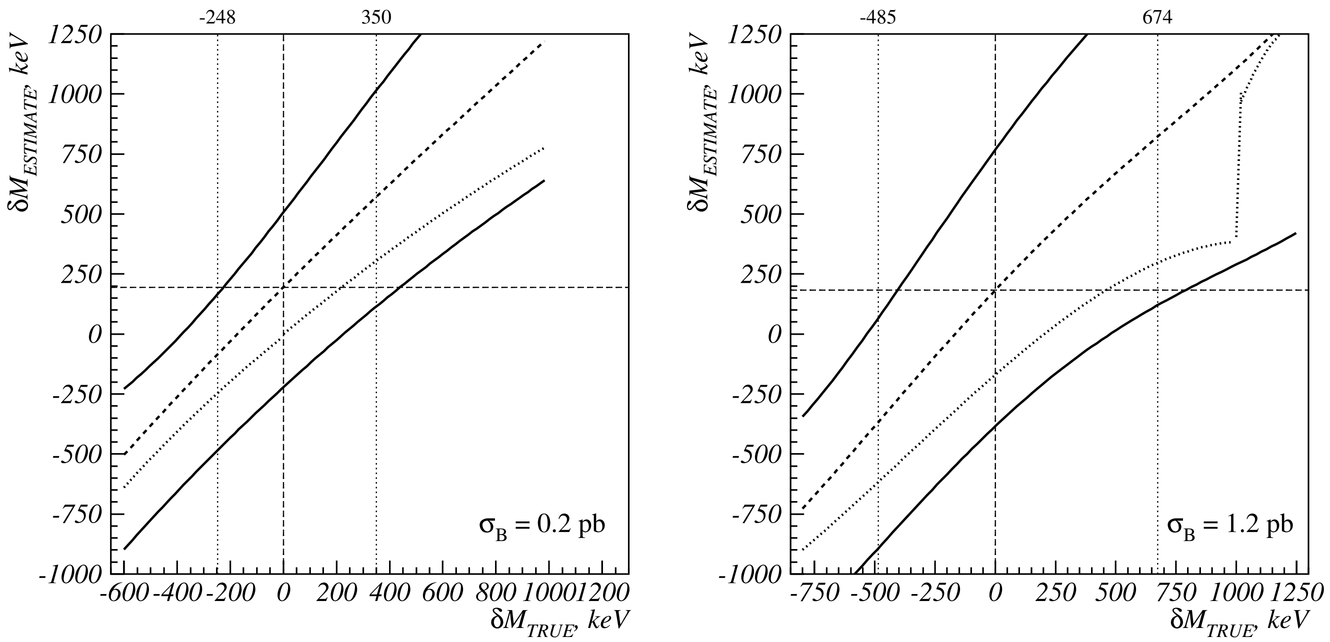
$$m_\tau = 1777.01^{+0.48}_{-0.24}$$

closer to the BES results

Statistical error reduces with exclusion of some data!

Is the error estimates according to $\Delta L = 0.5$ *rule correct?*

Neynman confidence belts for the two background levels (M.C.):



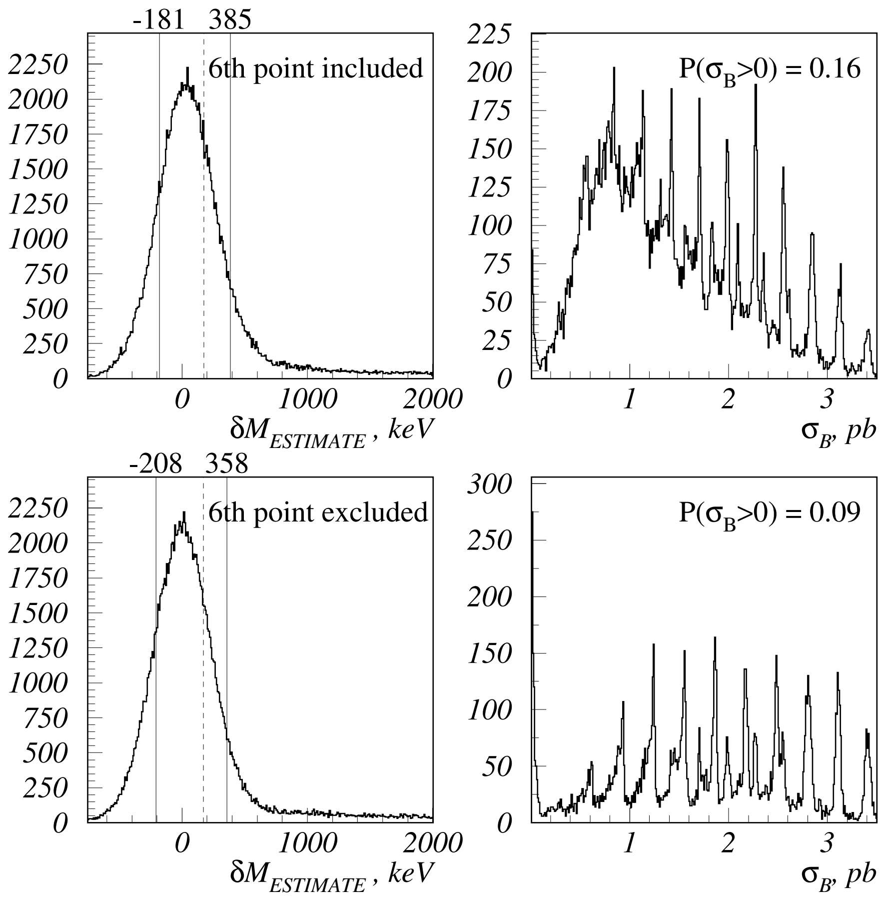
MINUIT gives reasonable error estimates (vertical dotted lines)

The mean value for a large number of simulated experiments is higher than the true one by ≈ 0.2 MeV!

Anomalous behavior of the statistical error and the bias of fitted mass value is an effect of the low statistics

(Bias of $0.2 \to 0.004$ MeV with simulated $\int Ldt = 5 \to 25 \times 5\ \mathrm{pb}^{-1}$)

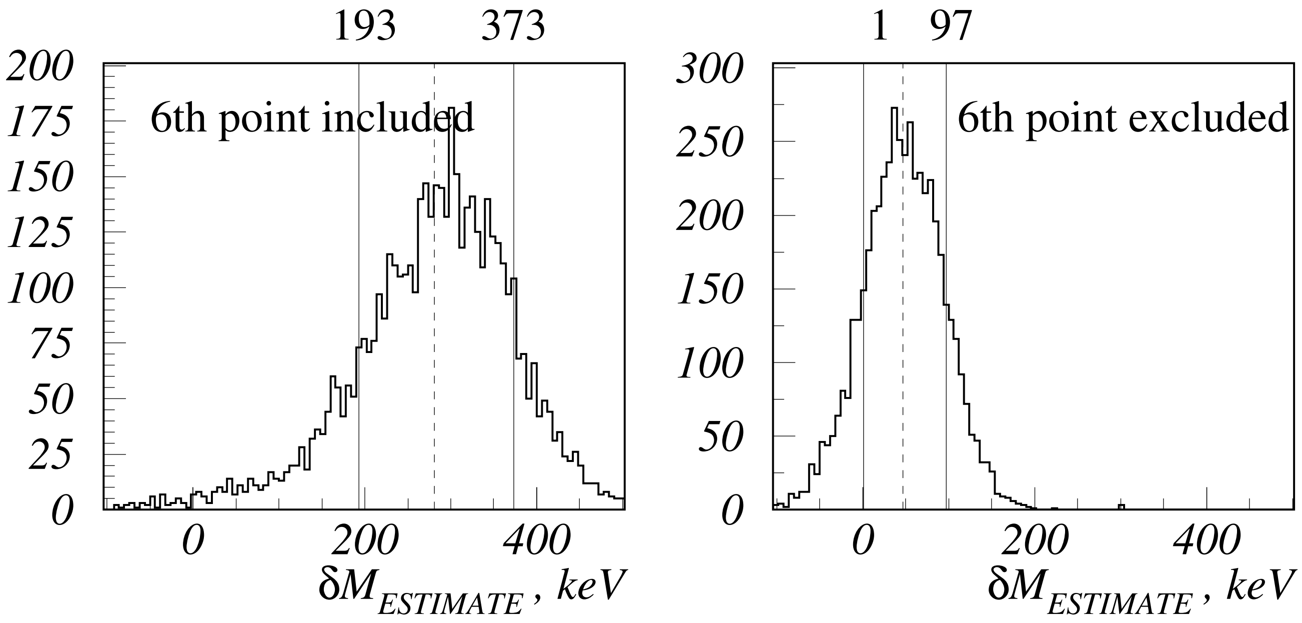
M.C. simulation of 16,000 experiments for $\sigma_B = 0$:



The statistical error reduction can be explained by the lower probability of the fake background appearance

One more reason to exclude 6th data point: sensitivity to the beam energy uncertainty δ_E

M.C. simulation for uncorrelated variation of data point energies:



$$\delta_E = 0.09 \text{ MeV}$$

$$\sigma_M = 0.18 \to 0.1 \text{ MeV}$$

Exclusion of 6th data point improve m_τ accuracy

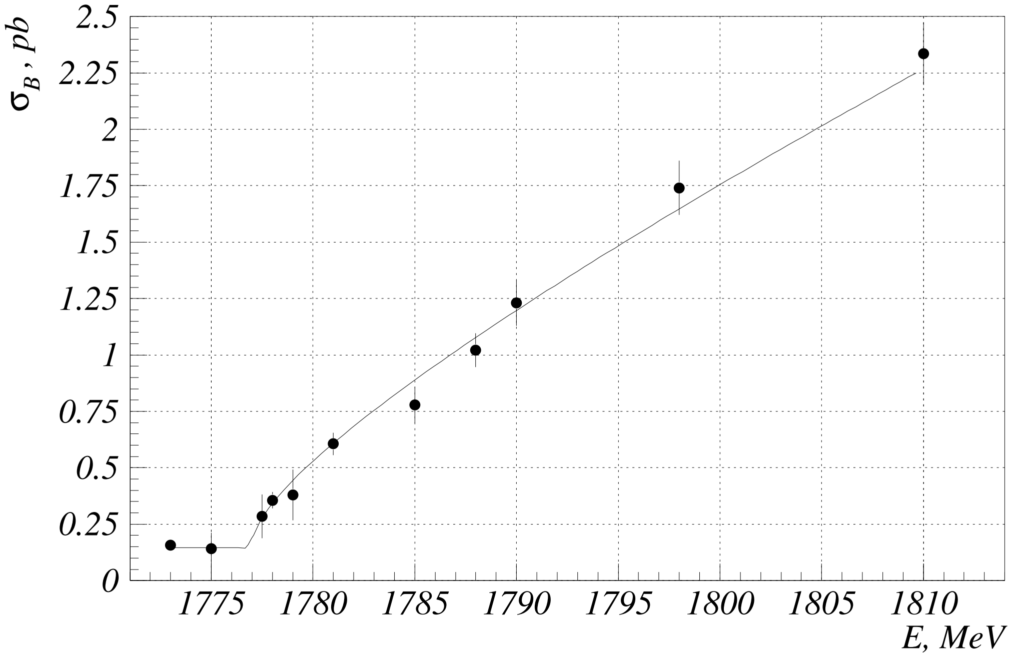
a s s u m i n g t h a t

the event observed in this point is not the background one

${}^{+0.66}_{-0.45} \to {}^{+0.48}_{-0.24}$ with the additional systematic error of 1777.24−1777.01 MeV

$\tau^+\tau^-$ selection criteria of BES depends on E_{beam}
(cuts on π momentum in $\tau \to \pi\bar{\nu}$ decay):

Our simulation of BES $\tau^+\tau^-$ background:



Particle level simulation with parameterized detector response and corrections to reproduce the signal cross section

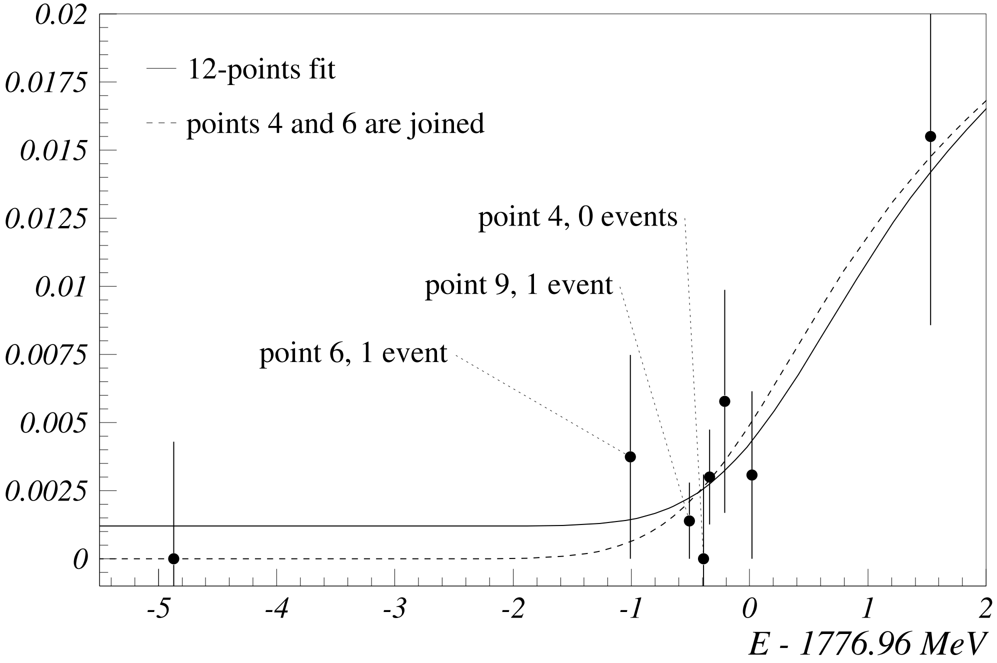
$e^+e^- \to e^+e^- + e^+e^-$ (ee)
$e^+e^- \to e^+e^- + \mu^+\mu^-$ $(e\mu, \mu\mu)$
$e^+e^- \to$ *hadrons* $(\pi\pi)$

M.C. simulation of experiments: $dm_{fit}/d\sigma_B \approx +90$ keV/pb
$\Rightarrow$ mass uncertainty of $^{+0}_{-0.1}$ MeV for $\sigma_B = 0^{+1.2}$

Mass uncertainty due to $\epsilon(E_{beam})$ dependence seems to be ± 0.01 MeV

Our result with 6th point removed differs from the BES one by 0.05 MeV

Contacts with persons responsible for BES τ mass analysis show that actual analysis procedure was not exactly described in the BES paper:



The data points number 6 and 4 were joined in the BES likelihood function!

Doing so, we reproduce the BES mass value with the accuracy of 0.01 MeV

Results of independent statistical analysis of the BES τ experiment:

The mass value most directly following from BES data

$$m_\tau = 1777.05\,^{+0.66}_{-0.49}\,^{+0.02}_{-0.10} \pm 0.14 = 1777.05\,^{+0.67}_{-0.52}\ \text{MeV}$$

With additional assumptions the statistical error can be reduced, so

$$m_\tau = 1776.83\,^{+0.48}_{-0.24}\,^{+0.02}_{-0.10}\,^{+0.23} \pm 0.14 = 1776.83\,^{+0.55}_{-0.30}\ \text{MeV}$$

These mass are corrected to the low statistic bias by -0.18 ± 0.02 MeV

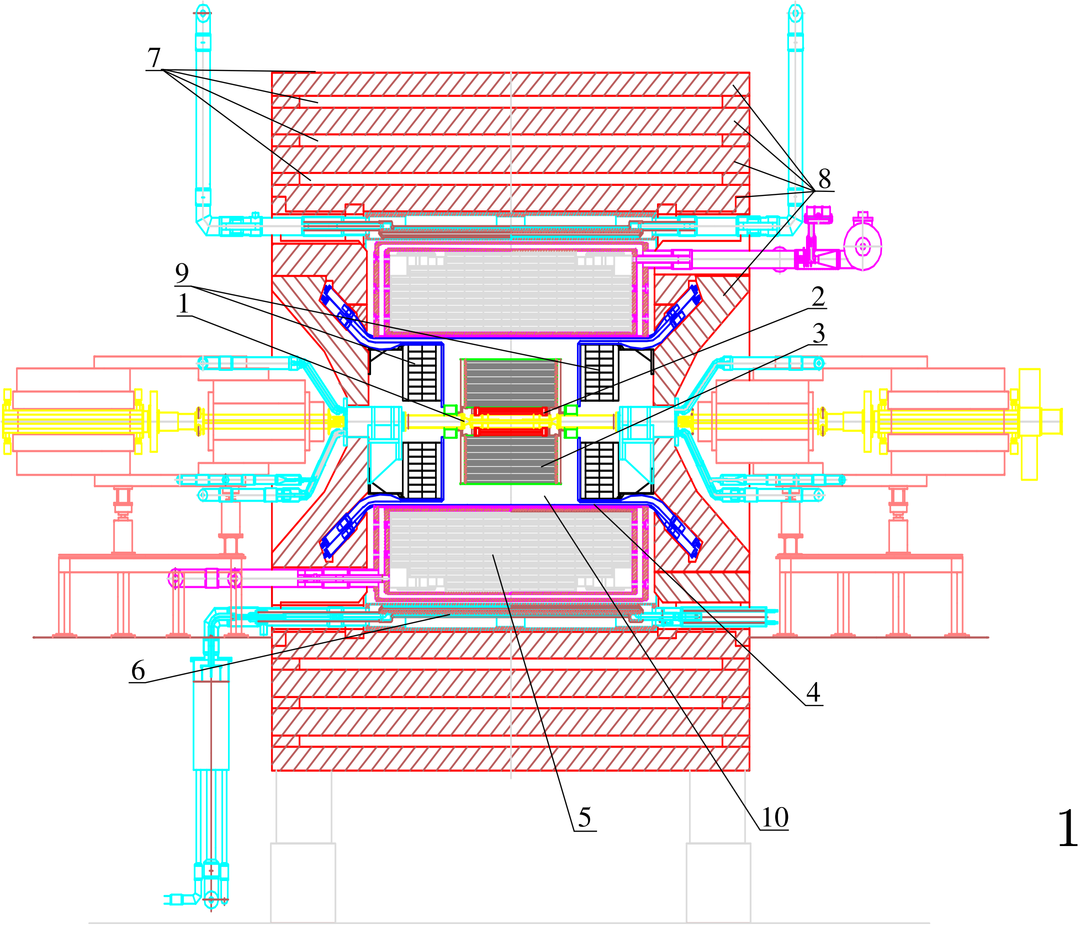
The accelerator-related uncertainty ± 0.14 MeV *are from the BES paper*

The published BES result is

$$m_\tau = 1777.05\,^{+0.18}_{-0.21}\,^{+0.25}_{-0.17} \pm 0.14 = 1776.96\,^{+0.31}_{-0.27}\ \text{MeV}$$

The confidence interval quoted by BES seems to be underestimated by the factor of 2÷1.5

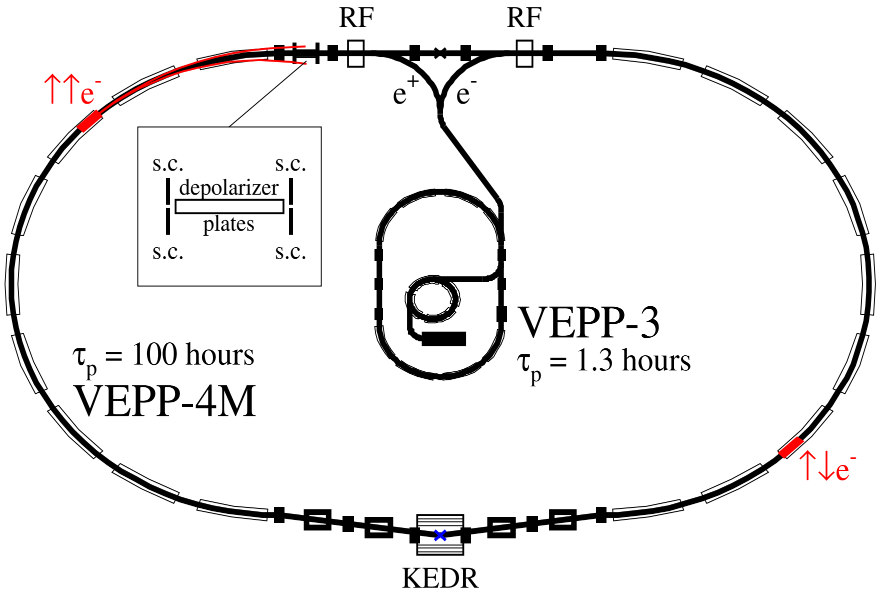
Planning KEDR/VEPP-4M experiment



KEDR detector:

1. Vacuum chamber
2. Vertex detector
3. Drift chamber
4. TOF scintillation counters
5. LKr barrel calorimeter
6. Superconducting coil (6 kGs)
7. Muon tubes
8. Magnet yoke
9. CsI end cap calorimeter
10. Aerogel Cherenkov counters

Energy calibration by **resonant depolarization method**

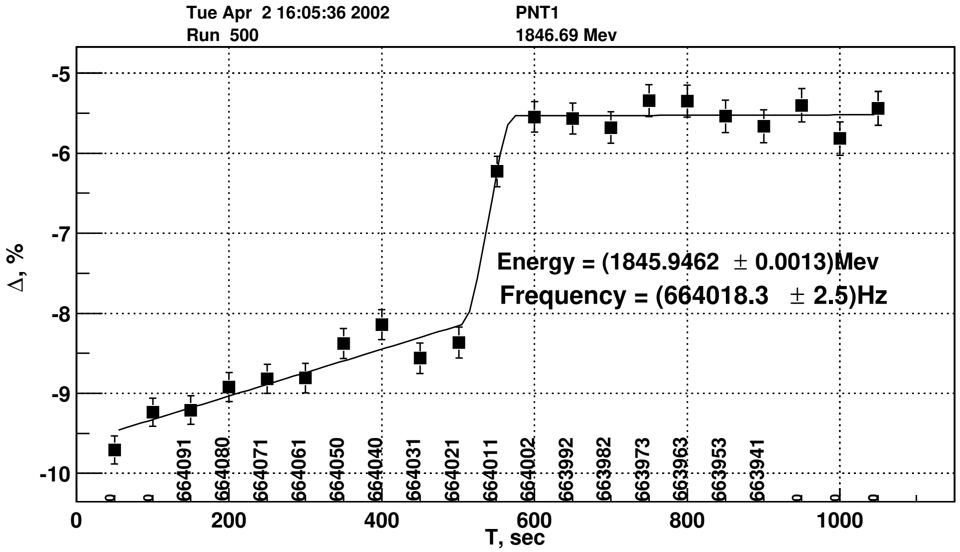


$$\Omega_{spin}/\omega_{rev} = 1 + \gamma \cdot \mu'/\mu_0$$

$$\Omega_{spin} \pm \Omega_{dep} = n \cdot \omega_{rev}$$

Touschek (intra-beam scattered) electron pairs are detected with $2{\times}2$ scintillation counters (s.c.).

"Two bunches" compensation technique: scattering rates from unpolarized ↑↓ and polarized ↑↑ beams are compared, $\Delta = (f_{pol} - f_{unpol})/f_{pol}$.



Application of resonant depolarization at VEPP-4M:

High precision measurement of J/ψ and ψ' masses (2002)

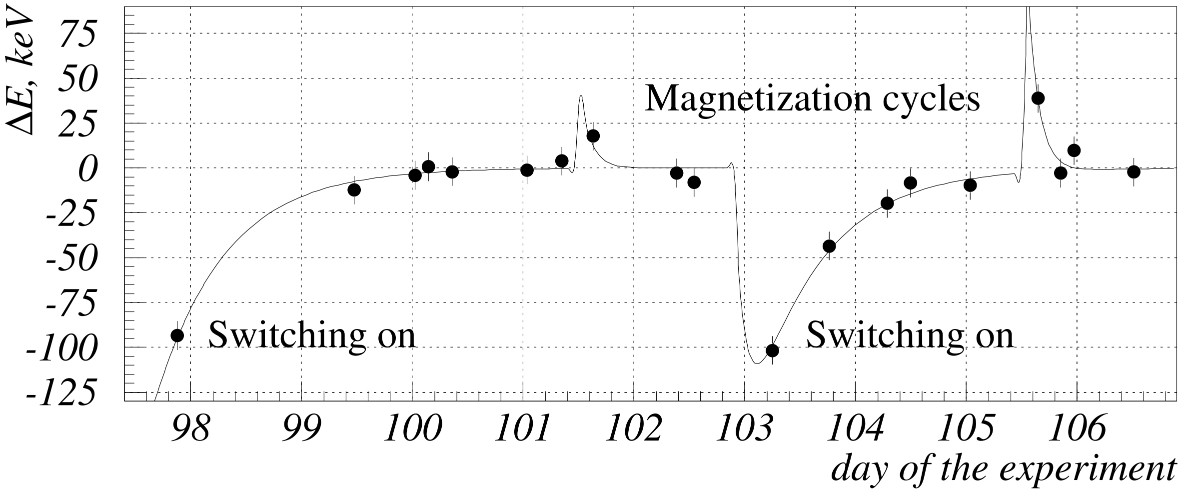
$$M_{J/\psi} = 3096.917 \pm 0.010 \pm 0.007 \text{ MeV}$$
$$M_{\psi'} = 3686.111 \pm 0.025 \pm 0.009 \text{ MeV}$$

Energy of data acquisition runs were determined as a function

$$E(E_{setup}(I), H_{NMR}, T_{ring}, \ldots, t)$$

interpolating the results of energy calibrations E_{ReDe}

Beam energy dependence on time due to switching on the ring and the magnetization cycles (*all other corrections are applied*):



A luckless scan of J/ψ:

$$E_{setup} = 1549.5 \div 1552.5 \text{ MeV}$$

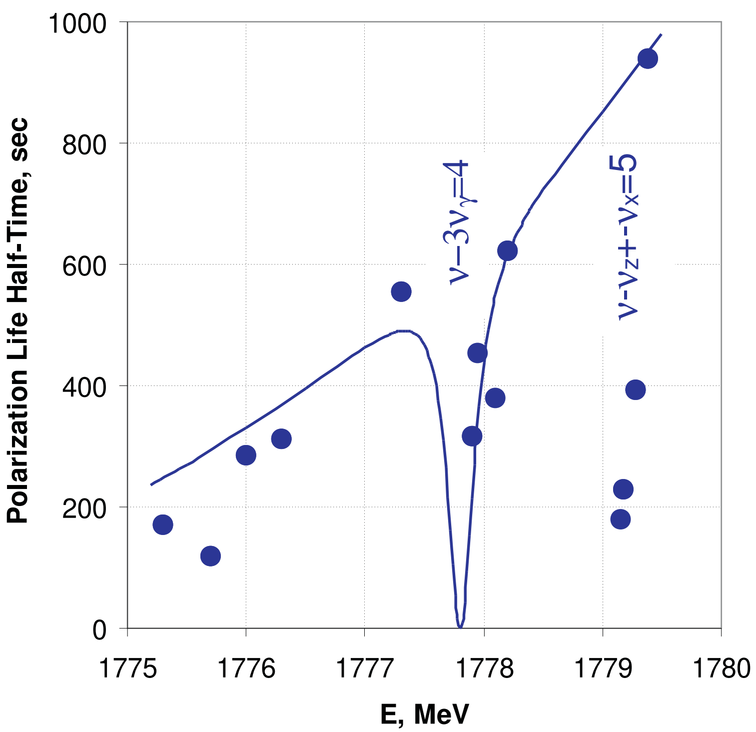
$$\sigma_{E_{ReDe}-E} \approx 7 \text{ keV}$$
$$\sigma_{E_{ReDe}-E_{setup}} \approx 170 \text{ keV}$$

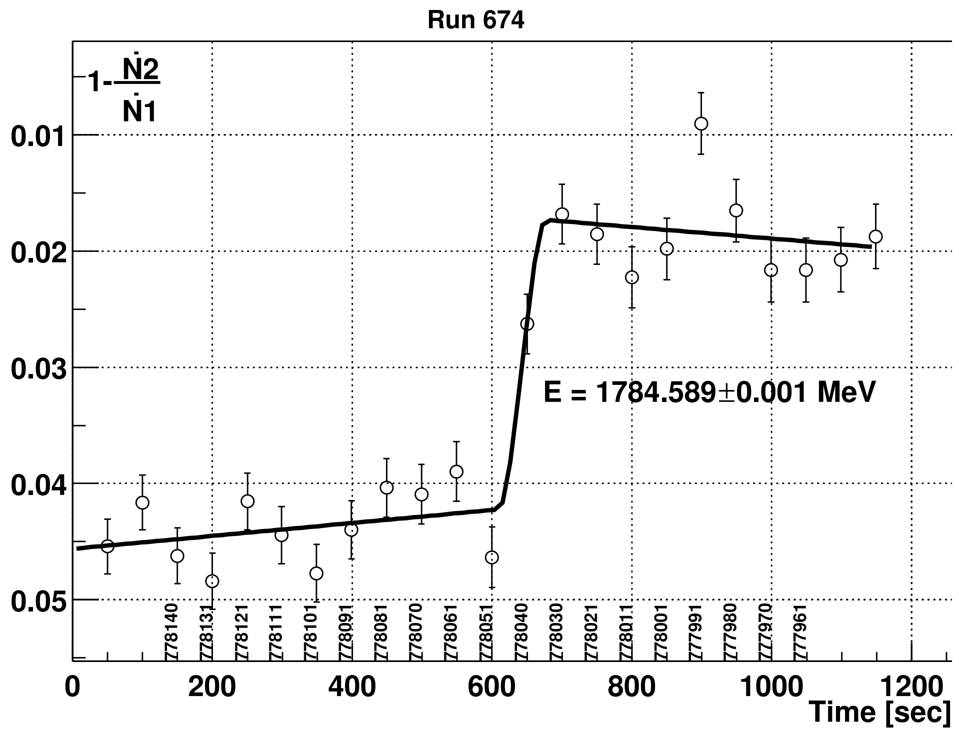
$$\Delta E = E_{ReDe} - E$$

Problems with resonant depolarization in τ energy region:

Integer spin resonance $\Omega_{spin} = 4 \times \omega_{rev}$ at $E \approx 1763$ MeV

$\Rightarrow$ below 1780 MeV the polarization life is very short:





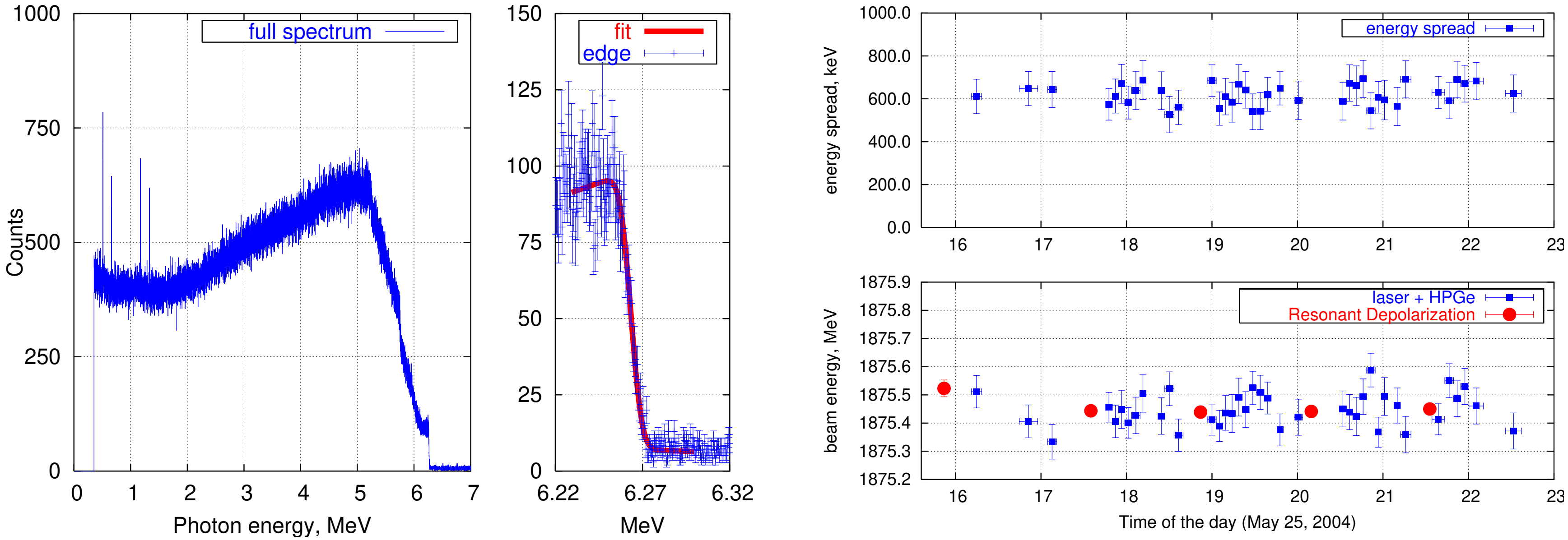
Reasonable energy calibration rate is once per a few days

Energy monitoring using Compton scattering of laser radiation

R.Klein *at al.*: NIM A384(1997)293, BESSY-I and BESSY-II

The method uses head-on interaction of CO_2 laser radiation ($\lambda = 10.591\ \mu$m) with the electron beam. The energy spectrum of backscattered photons is measured by large-volume germanium detector.

N.Yu. Muchnoi: SR-2004, first VEPP-4M results:



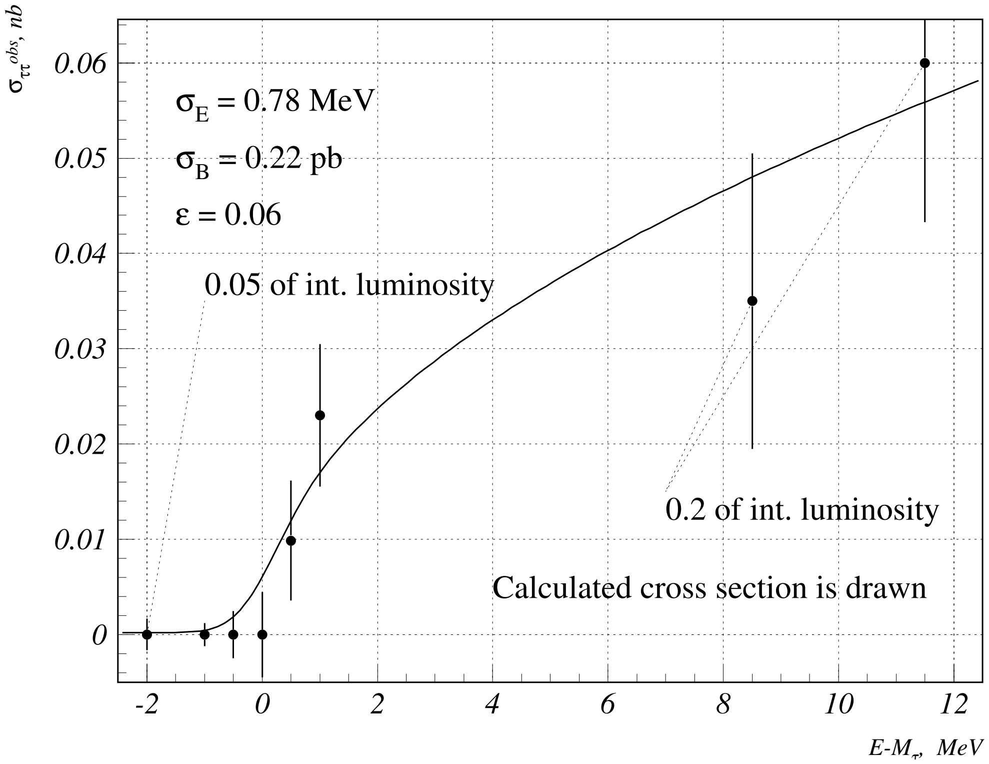
Accuracy of the energy determination $\approx$ 0.1 MeV for a 10-minutes run

About event selection:

Very preliminary estimates of the detection efficiency and the background cross section for $\tau\tau \to eX$ with $X = \mu, \pi, K$:

$$\epsilon \approx 0.06, \quad \sigma_B = 0.2 \div 0.3 \text{ pb}^{-1}$$

Possible scanning scenario:



5 points around W.A. m_τ covering ± 1 MeV, $\int L dt = 2$ pb^{-1}
$\Rightarrow \sigma_m \approx 0.31$ MeV

3 points closest to m_τ obtained covering ± 0.5 MeV, $\int L dt = 3$ pb^{-1}
$\Rightarrow \sigma_m \approx 0.21$ MeV

Resulting $\sigma_m \approx 0.18$ MeV
Gain of about 10%

Time schedule:

♡ Start at the beginning of 2005 ♡

VEPP-4M luminosity at the τ threshold $\sim 1\cdot 10^{30}$

With the 100% efficiency of the VEPP-3/VEPP-4M facility about 2 months is required to collect 5 pb^{-1}. The absolute energy monitoring will take 10÷15% of the time. A few J/ψ and ψ' scans should be performed to control the beam energy spread. About 25% of the time the VEPP-3/VEPP-4M works for S.R. experiments.

♠ Finishing at the end of 2005? ♠

Conclusion

Independent statistical analysis of the BES τ threshold experiment has been performed.

By our opinion
the mass value most directly following from BES data is

$$m_\tau = 1777.05\,^{+0.66}_{-0.49}\,^{+0.14}_{-0.17} = 1777.05\,^{+0.67}_{-0.52}\ \mathrm{MeV},$$

the mass error can be reduced by exclusion of one data point of 12:

$$m_\tau = 1776.83\,^{+0.48}_{-0.24}\,^{+0.27}_{-0.17} \pm 0.14 = 1776.83\,^{+0.55}_{-0.30}\ \mathrm{MeV}.$$

The confidence interval of $^{+0.31}_{-0.27}$ quoted by BES seems to be underestimated by the factor of $2\div1.5$

New τ threshold experiment with the KEDR detector at the VEPP-4M collider is under preparation and should start at the beginning of 2005.

The expected τ lepton mass accuracy is about 0.2 MeV.