Recent Results from the KEDR Detector

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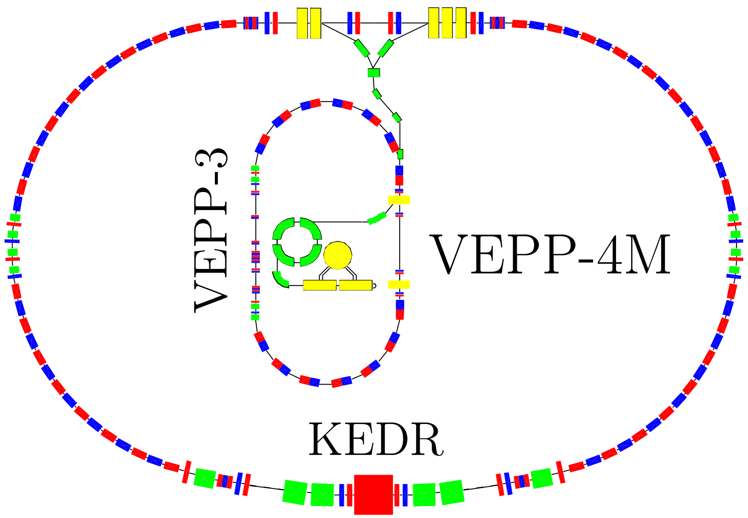
Outline

1. Leptonic widths of the J/ψ
2. D meson masses
3. Conclusions

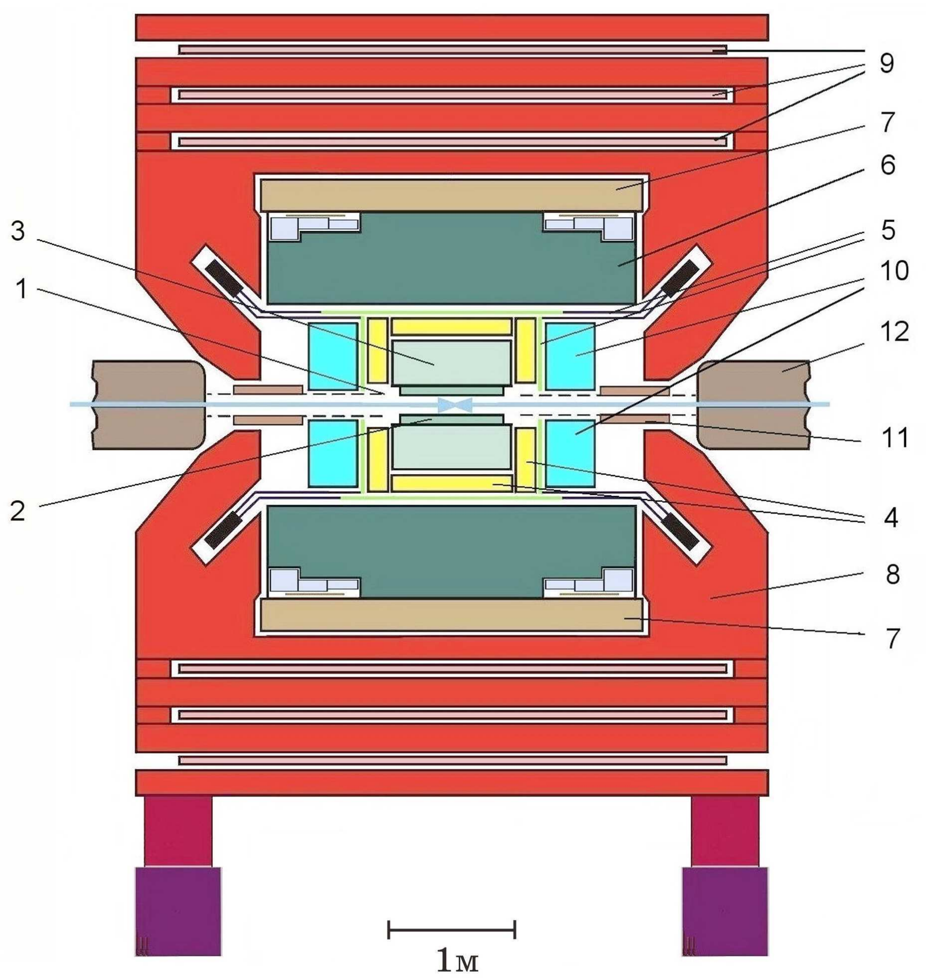
VEPP–4M collider



Circumference	366 m
Beam energy	1÷6 GeV
Number of bunches	2 × 2
Luminosity, $E = 1.5$ GeV	2×10^{30} cm^{-2}s^{-1}
Luminosity, $E = 5.0$ GeV	2×10^{31} cm^{-2}s^{-1}

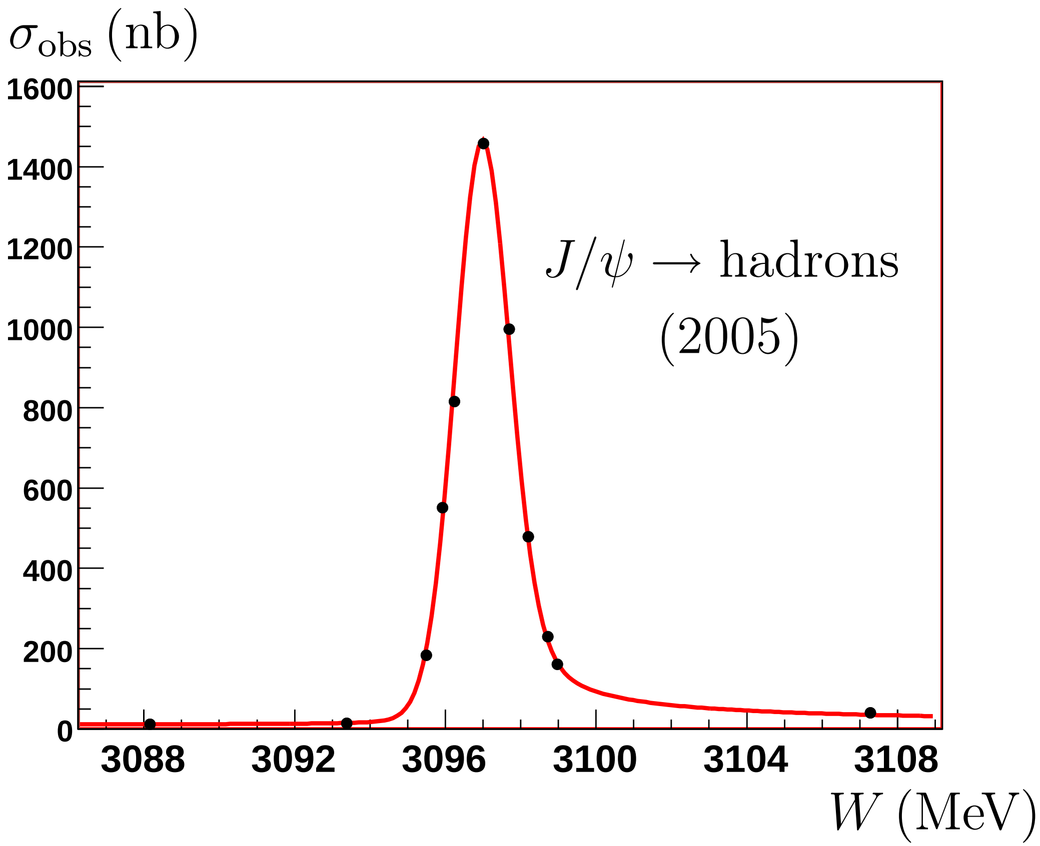
- Resonant depolarization technique:
  Instantaneous measurement accuracy $\simeq 1 \times 10^{-6}$
  Energy interpolation accuracy $(5 \div 15) \times 10^{-6}$ $(10 \div 30$ keV$)$
- Infrared light Compton backscattering:
  Statistical accuracy $\simeq 5 \times 10^{-5}$ / 30 minutes
  Systematic uncertainty $\simeq 3 \times 10^{-5}$ $(50 \div 70$ keV$)$

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
8. Magnet yoke
9. Muon tubes
10. CsI calorimeter
11. Compensation solenoid
12. VEPP–4M quadrupole

Leptonic Width Determination



A precise scan of the J/ψ ($\sim 2.5 \times 10^5$) can be used to measure leptonic widths or more exactly $\Gamma_{e^+e^-}\mathcal{B}_l$, a basis for $\Gamma_{e^+e^-}$ and $\mathcal{B}_{l^+l^-}$, $l = e,\ \mu$

Theoretical basis for $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ at J/ψ

The cross section of $e^+e^- \to e^+e^-$ in the soft photon approximation

$$\left(\frac{d\sigma}{d\Omega}\right)_{th} = \frac{1}{M^2}\left\{\frac{9}{4}\frac{\Gamma_{ee}^2}{\Gamma M}\left(1+\frac{3}{4}\beta\right)(1+\cos^2\theta)\,\Im f - \frac{3\alpha}{2}\frac{\Gamma_{ee}}{M}\left[(1+\cos^2\theta) - \frac{(1+\cos^2\theta)^2}{(1-\cos\theta)}\right]\Re f\right\} + \left(\frac{d\sigma}{d\Omega}\right)_{\rm QED},$$

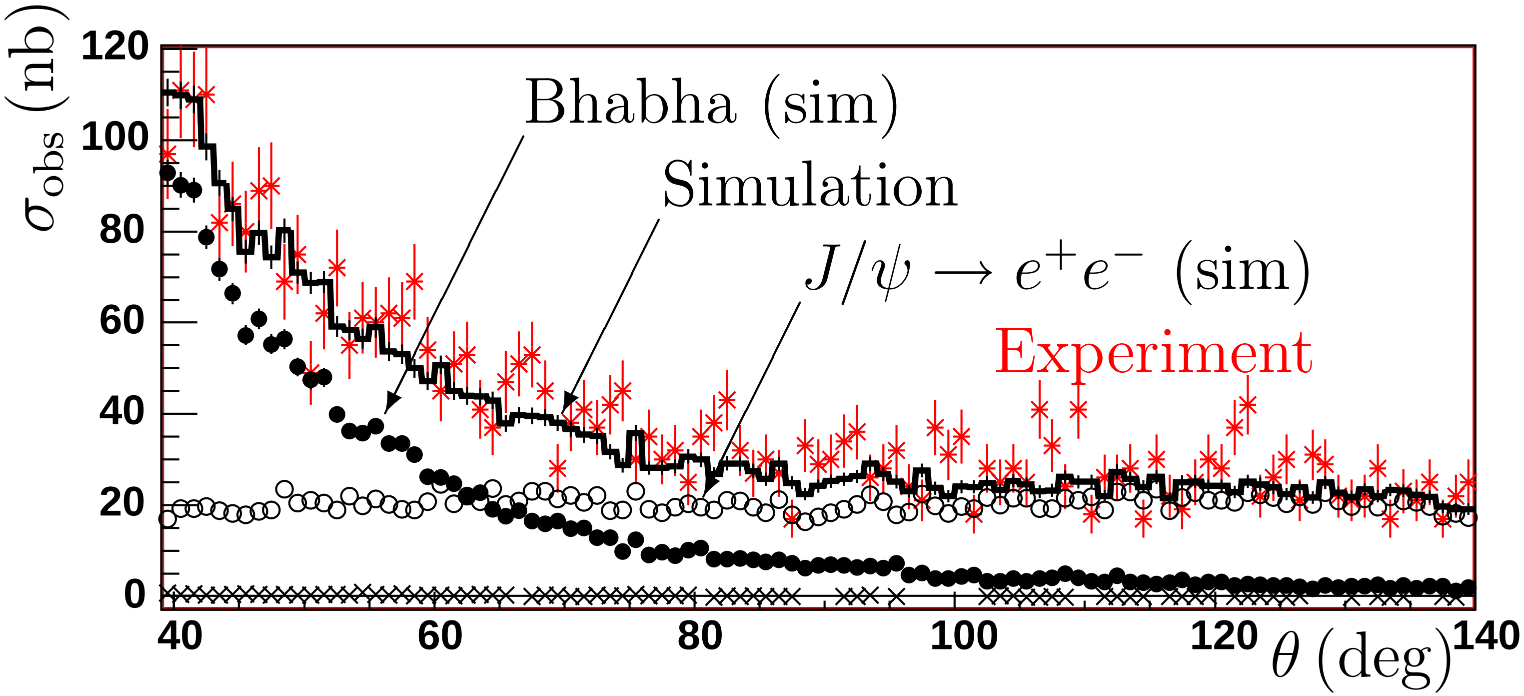
where $f = \left(\dfrac{\frac{M}{2}}{-W+M-\frac{i\Gamma}{2}}\right)^{1-\beta}, \quad \beta = \dfrac{4\alpha}{\pi}\left(\ln\dfrac{W}{m_e} - \dfrac{1}{2}\right) \simeq 0.077$

Ya. Azimov et al. JETP Lett. 21 (1975) 172

Taking into account the c.m.s. energy spread σ_W:

$$\sigma(W) = \frac{1}{\sqrt{2\pi}\sigma_W}\int \sigma_{th}(W')e^{\left\{-\frac{(W-W')^2}{2\sigma_W^2}\right\}}dW'$$

$d\sigma/d\Omega$ for $e^+e^- \to e^+e^-$ at J/ψ



$$N_{\rm exp}(E_i,\theta) = \mathcal{R}_{\mathcal{L}} \times \mathcal{L}(E_i) \times \Big(\sigma^{\rm th}_{\rm peak}(E_i,\theta)\cdot\epsilon^{\rm sim}_{\rm peak}(E_i,\theta) +$$

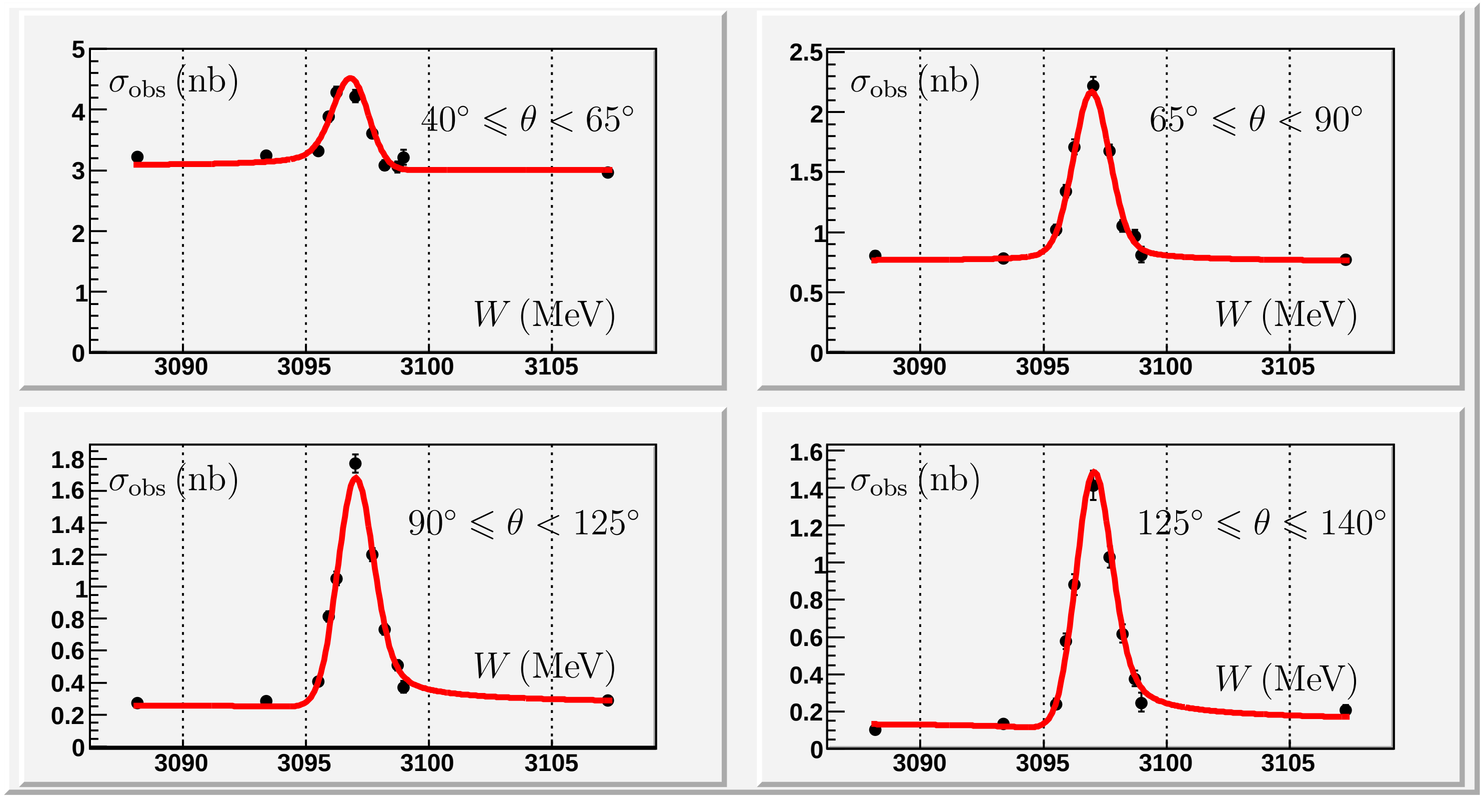
$$+\sigma^{\rm th}_{\rm inter}(E_i,\theta)\cdot\epsilon^{\rm sim}_{\rm inter}(E_i,\theta) + \sigma^{\rm sim}_{\rm Bhabha}(E_i,\theta)\cdot\epsilon^{\rm sim}_{\rm Bhabha}(E_i,\theta)\Big),$$

where $\sigma^{\rm th}_{\rm peak}(E_i,\theta) \sim \Gamma_{ee}\times\Gamma_{ee}/\Gamma$

Systematic errors for $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ at J/ψ

Source	σ, %	Source	σ, %
Peak position	< 0.1	Angle θ	0.2
Energy spread	0.2	Interference	0.2
Energy per point	0.3	Bhabha MC	0.4
DC selection	0.7	PHOTOS	0.4
LKr selection	0.2	BG from $J/\psi \to$ hadrons	0.2
Luminosity	0.8	Fit	0.2
Trigger	0.5	Total	1.4

Cross Section of $e^+e^- \to e^+e^-$ at J/ψ



$$\Gamma_{ee} \times \Gamma_{ee}/\Gamma_{\mathrm{total}} = 0.3355 \pm 0.0064 \pm 0.0048\,\mathrm{keV}$$

Comparison of $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ Measurements at J/ψ

Group	Year	Γ^2_{ee}/Γ, keV
NaI/SLAC	1975	0.36 ± 0.10
MEA	1975	0.34 ± 0.09
$\gamma\gamma 2$	1975	0.32 ± 0.07
DASP	1979	0.35 ± 0.02
KEDR	2009	$0.3355 \pm 0.0064 \pm 0.0048$

The precision of our $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ is 2.4%,
comparable to the world averages of $\Gamma_{e^+e^-}$ (2.6%) and $\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}/\Gamma$ (2.1%)

It agrees well with $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma = 0.3291 \pm 0.0090$ keV
obtained using $\Gamma_{e^+e^-}$ and Γ from PDG-08

Theoretical basis for $\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}/\Gamma$ at J/ψ

The cross section of $e^+e^- \to \mu^+\mu^-$ in the soft photon approximation

$$\left(\frac{d\sigma}{d\Omega}\right)^{ee\to\mu\mu} = \frac{3}{4M^2}\left(1+\cos^2\theta\right)\left\{\frac{3\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}}{\Gamma M}\left(1+\frac{3}{4}\beta\right)\Im\mathcal{F} - \right.$$
$$\left. - \frac{2\alpha\sqrt{\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}}}{M}\left(1+\frac{11}{12}\beta\right)\Re\mathcal{F}\right\} + \left(\frac{d\sigma}{d\Omega}\right)^{ee\to\mu\mu}_{\rm QED},$$

$$\text{where} \quad f = \left(\frac{\frac{M}{2}}{-W+M-\frac{i\Gamma}{2}}\right)^{1-\beta}, \quad \beta = \frac{4\alpha}{\pi}\left(\ln\frac{W}{m_e}-\frac{1}{2}\right) \simeq 0.077$$

Ya. Azimov et al. JETP Lett. 21 (1975) 172

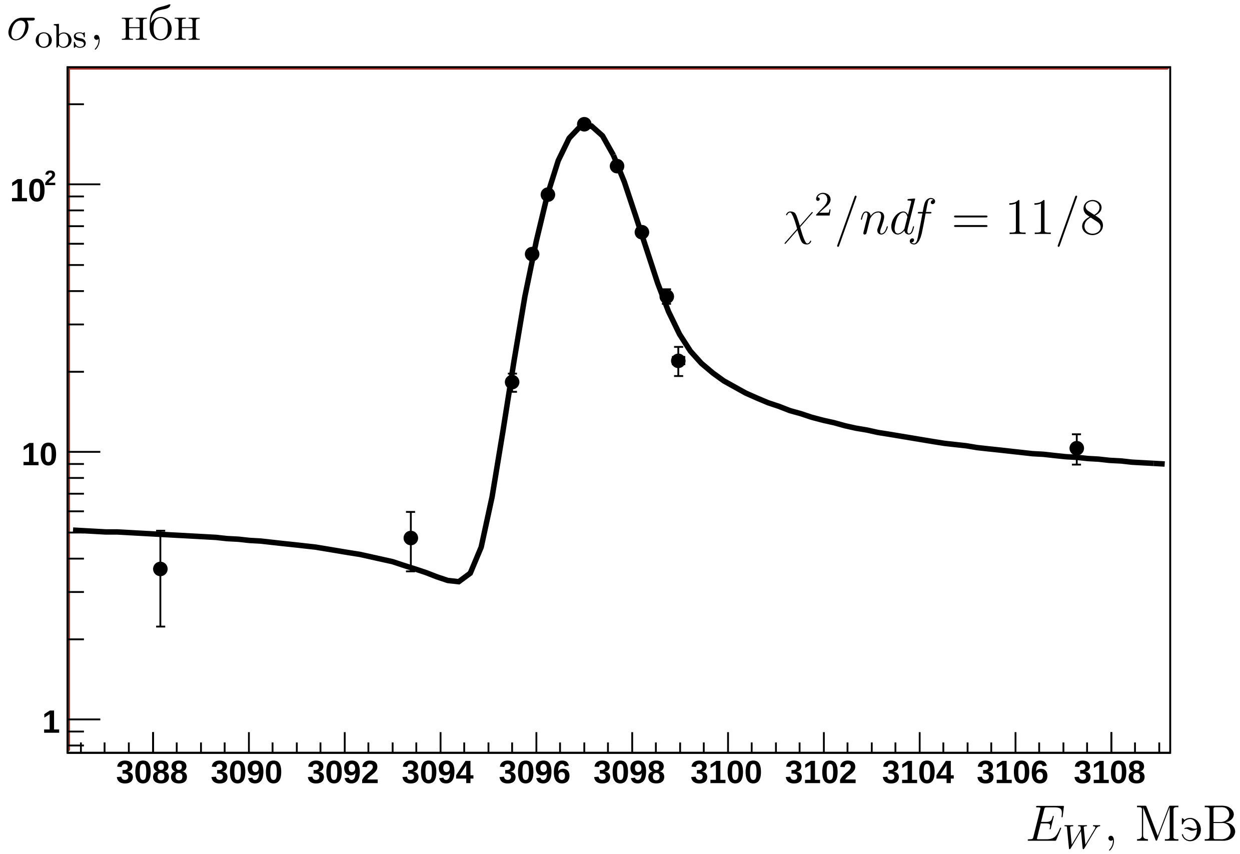
Taking into account the c.m.s. energy spread σ_W:

$$\sigma(W) = \frac{1}{\sqrt{2\pi}\sigma_W}\int \sigma_{th}(W')e^{\left\{-\frac{(W-W')^2}{2\sigma_W^2}\right\}}dW'$$

Systematic uncertainties for $\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}/\Gamma$ at J/ψ

Source	$\sigma, \%$	Source	$\sigma, \%$
Energy spread	0.5	Angle θ	0.2
Energy per point	0.5	Bhabha MC	0.6
$\epsilon_{ee} \neq \epsilon_{\mu\mu}$	0.8	PHOTOS	0.5
L calibration (abs.)	0.7	BG (non-resonant)	0.1
L measurement (rel.)	0.8	BG from $J/\psi \to$ hadrons	0.6
Trigger	0.5	Total	1.9

Cross Section of $e^+e^- \to \mu^+\mu^-$ at J/ψ



$$\Gamma_{e^+e^-} \times \Gamma_{\mu^+\mu^-}/\Gamma = 0.3350 \pm 0.0052 \pm 0.0063 \text{ keV}$$

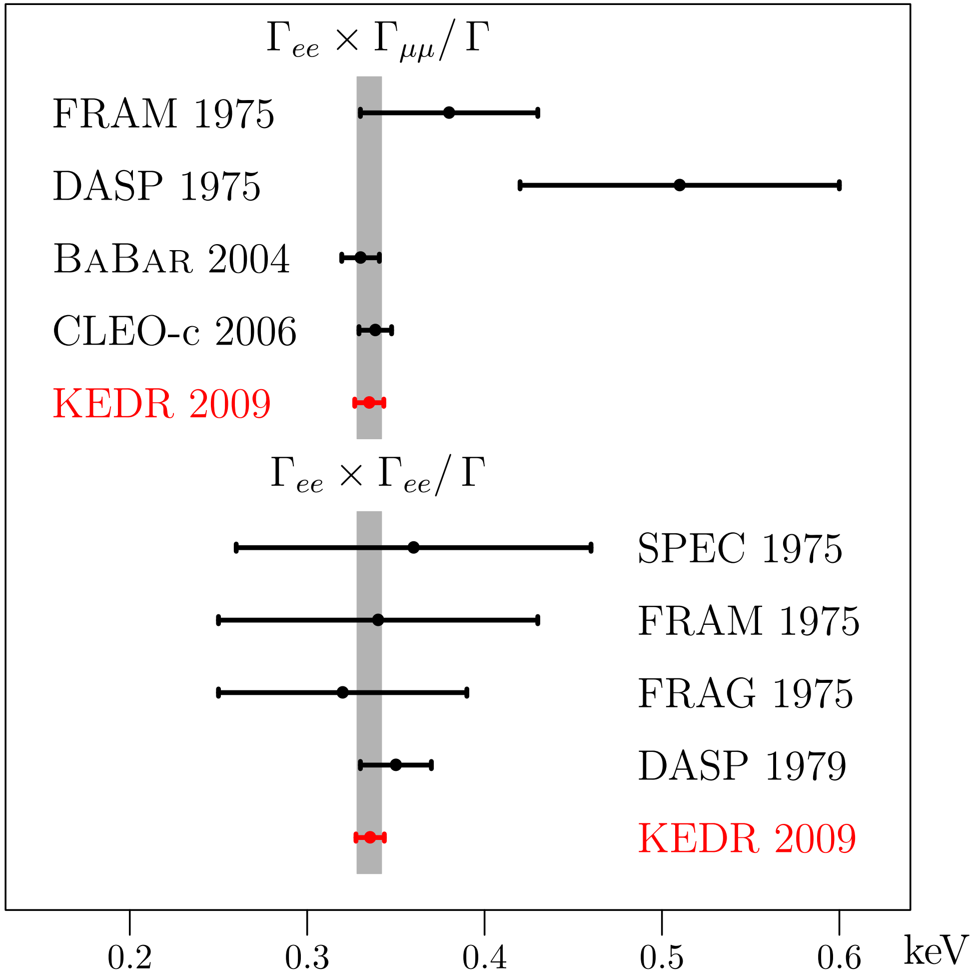
Comparison of $\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}/\Gamma$ Measurements at J/ψ

Group	Year	$\Gamma_{ee}\Gamma_{\mu\mu}/\Gamma$, keV
FRAM	1975	0.36 ± 0.05
DASP	1975	0.51 ± 0.09
BaBar	2004	$0.3301 \pm 0.0077 \pm 0.0073$
CLEO	2006	$0.3384 \pm 0.0058 \pm 0.0071$
KEDR	2009	$0.3350 \pm 0.0052 \pm 0.0063$

The precision of our $\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}/\Gamma$ is 2.4%,
comparable to the world average of 2.1%

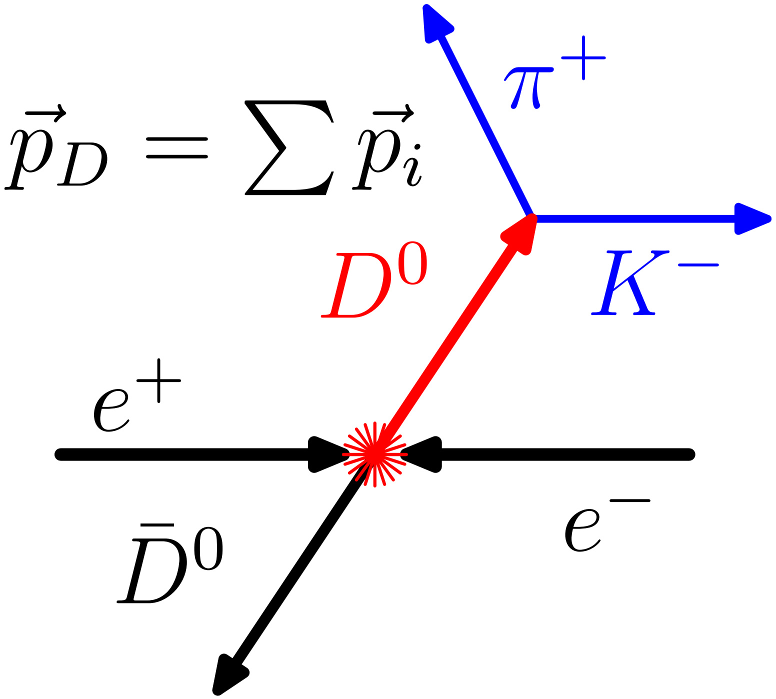
It agrees well with 0.335 ± 0.007 keV from PDG-08

Comparison of $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ and $\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}/\Gamma$ at J/ψ



Measurement of D-meson masses

D-mesons from $e^+e^- \to \psi(3770) \to D\overline{D}$ with 0.9 pb^{-1}

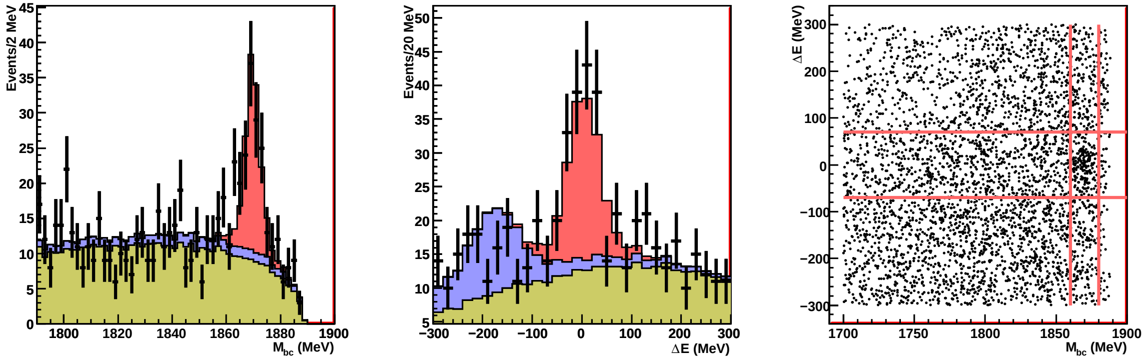


One of the D's is reconstructed:

$D^0 \to K^-\pi^+ \quad \mathcal{B} = (3.89 \pm 0.05)\%$
$D^+ \to K^-\pi^+\pi^+ \quad \mathcal{B} = (9.22 \pm 0.21)\%$
$M_D = \sqrt{E^2_{beam} - p^2_D}$,
$\Delta E = \sum_i \sqrt{p^2_i + m^2_i} - E_{beam}$,
$\vec{p}_D = \sum_i \vec{p}_i$.

$D^\pm$ meson mass is obtained from a 2D fit in $(M_D, \Delta E)$,
that of D^0 from a 3D fit in $((M_D, \Delta E, |\Delta p|)$.

$D^{\pm}$ mass measurement

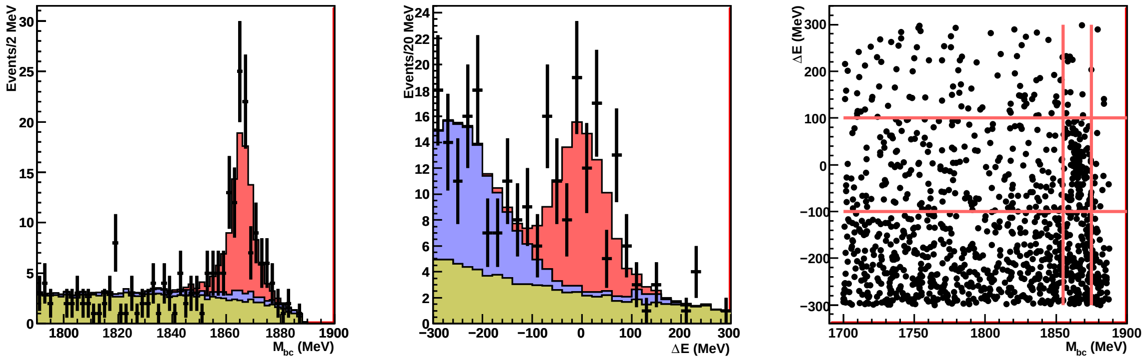


$116 \pm 16\ D^+ \to K^- \pi^+ \pi^+$ events $\Rightarrow$ $m_{D^{\pm}} = 1869.32 \pm 0.48 \pm 0.22\ \mathrm{MeV}/c^2$

Dominant systematic errors:

- Signal shape (0.11 MeV)
- Background shape (0.11 MeV)
- Radiative corrections (0.11 MeV)
- Momentum calibration (0.10 MeV)

D^0 mass measurement



$94 \pm 13\ D^0 \to K^-\pi^+$ events $\Rightarrow$ $m_{D^0} = 1865.53 \pm 0.39 \pm 0.25\ \text{MeV}/c^2$

Dominant systematic errors:

- Signal shape (0.11 MeV)
- Background shape (0.06 MeV)
- Radiative corrections (0.17 MeV)
- Momentum calibration (0.10 MeV)

Comparison of D^0 and $D^\pm$ Mass Measurements – I

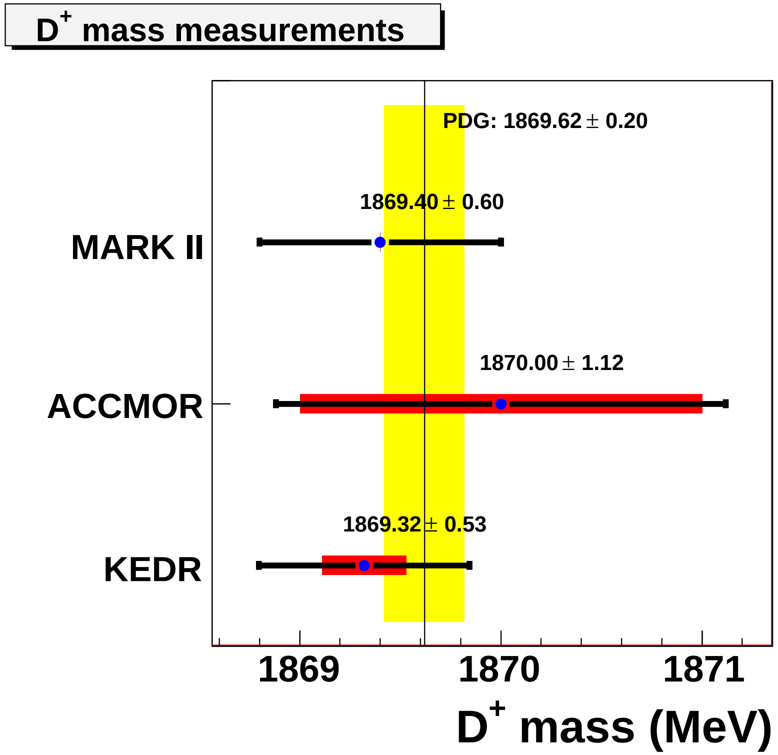
$D^\pm$ Mass Measurement

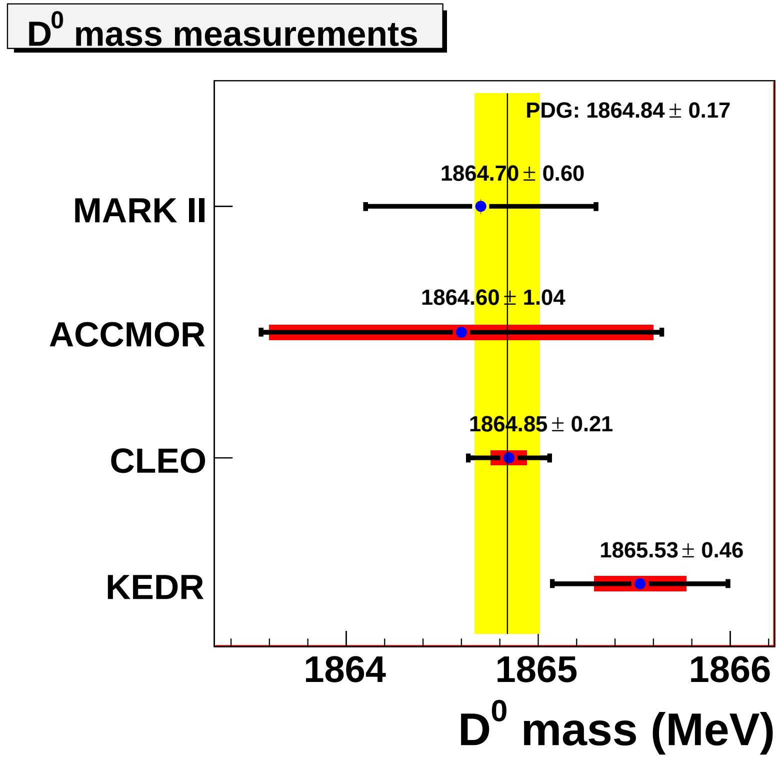
Group	Year	Mass, MeV	Method
LGW, MARKII	1981	1869.4 ± 0.6	$e^+e^- \to D\bar{D}$ 3.77 GeV
ACCMORE	1990	$1870.0 \pm 0.5 \pm 1.0$	$\pi^- Cu$ 230 GeV
PDG	2008	1869.62 ± 0.20	Fit of M_{D^0}, $M_{D^\pm}$, $M_{D_s}, \ldots$
KEDR	2008	$1869.32 \pm 0.48 \pm 0.22$	$e^+e^- \to D\bar{D}$ 3.77 GeV

D^0 Mass Measurement

Group	Year	Mass, MeV	Method
LGW, MARKII	1981	1864.7 ± 0.6	$e^+e^- \to D\bar{D}$ 3.77 GeV
ACCMORE	1990	$1864.6 \pm 0.3 \pm 1.0$	$\pi^- Cu$ 230 GeV
CLEO	2007	$1864.847 \pm 0.190 \pm 0.095$	$D^0 \to K^0_S \phi$
PDG	2008	1864.84 ± 0.17	–
KEDR	2008	$1865.53 \pm 0.39 \pm 0.25$	$e^+e^- \to D\bar{D}$ 3.77 GeV

Comparison of D^0 and $D^{\pm}$ Mass Measurements – II





Conclusions

1. $\Gamma_{e^+e^-}\mathcal{B}_{ll}$ of the J/ψ measured with high precision:
   - $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma = (0.3355 \pm 0.0064 \pm 0.0048)$ keV
   - $\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}/\Gamma = (0.3350 \pm 0.0052 \pm 0.0063)$ keV
2. $D^\pm$ and D^0 masses measured:
   - $m(D^\pm) = 1869.32 \pm 0.48 \pm 0.22$ MeV Best direct m-nt
   - $m(D^0) = 1865.53 \pm 0.39 \pm 0.25$ MeV
3. To be reported at LP-09:
   - $m(J/\psi) = 3096.924 \pm 0.010 \pm 0.017$ MeV
   - $m(\psi(2S)) = 3686.122 \pm 0.008 \pm 0.012$ MeV
   - Precise measurement of $m(\psi(3770))$, $\Gamma(\psi(3770))$, $\Gamma_{ee}(\psi(3770))$
   - Search for narrow resonances at $2.0 < \sqrt{s} < 3.1$ GeV

Back-up

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

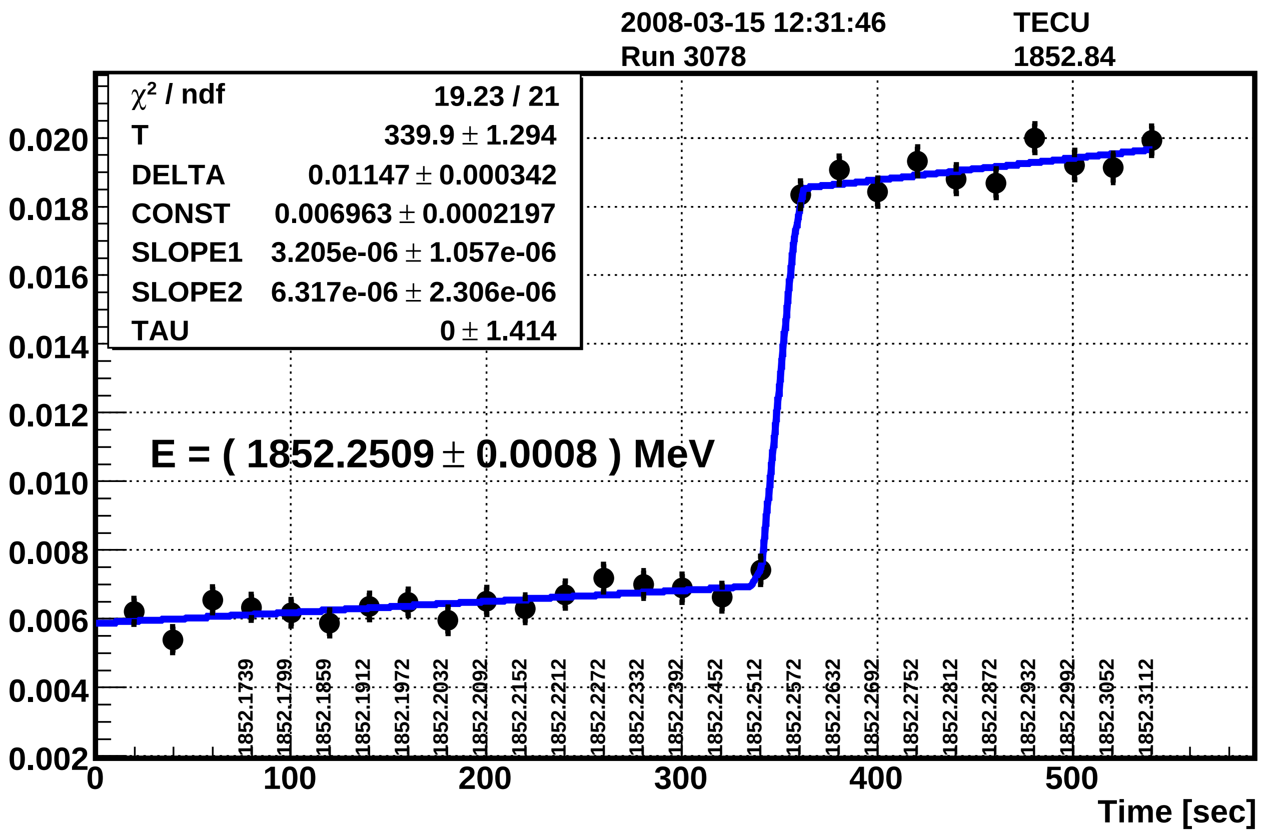
Since 1975 has been successfully used

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

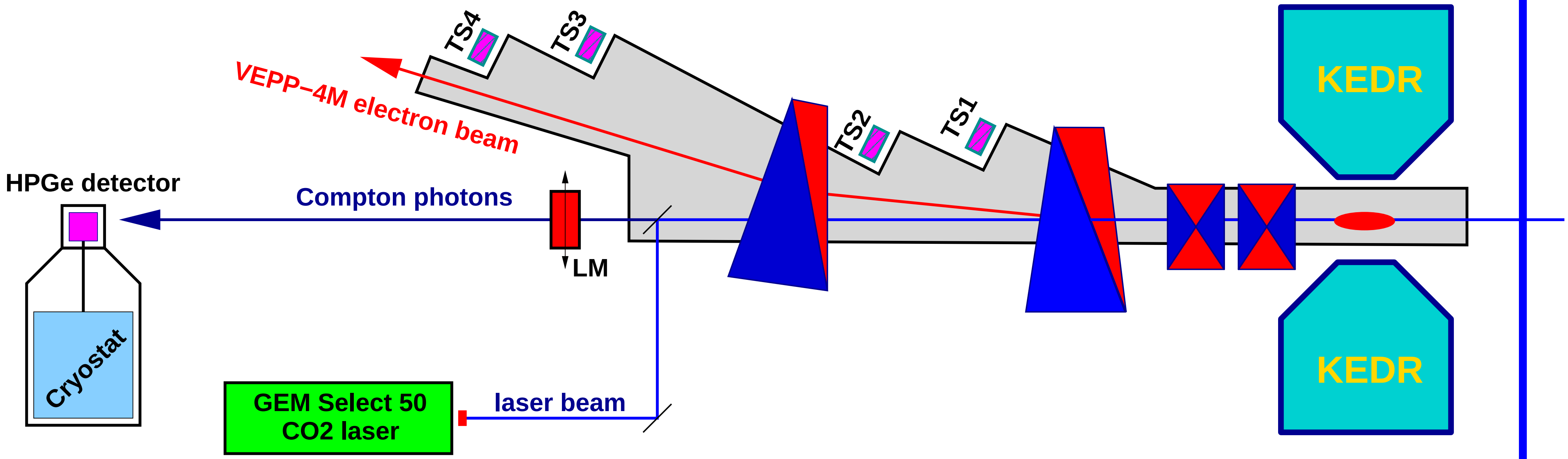
Typical RD Run at VEPP-4M



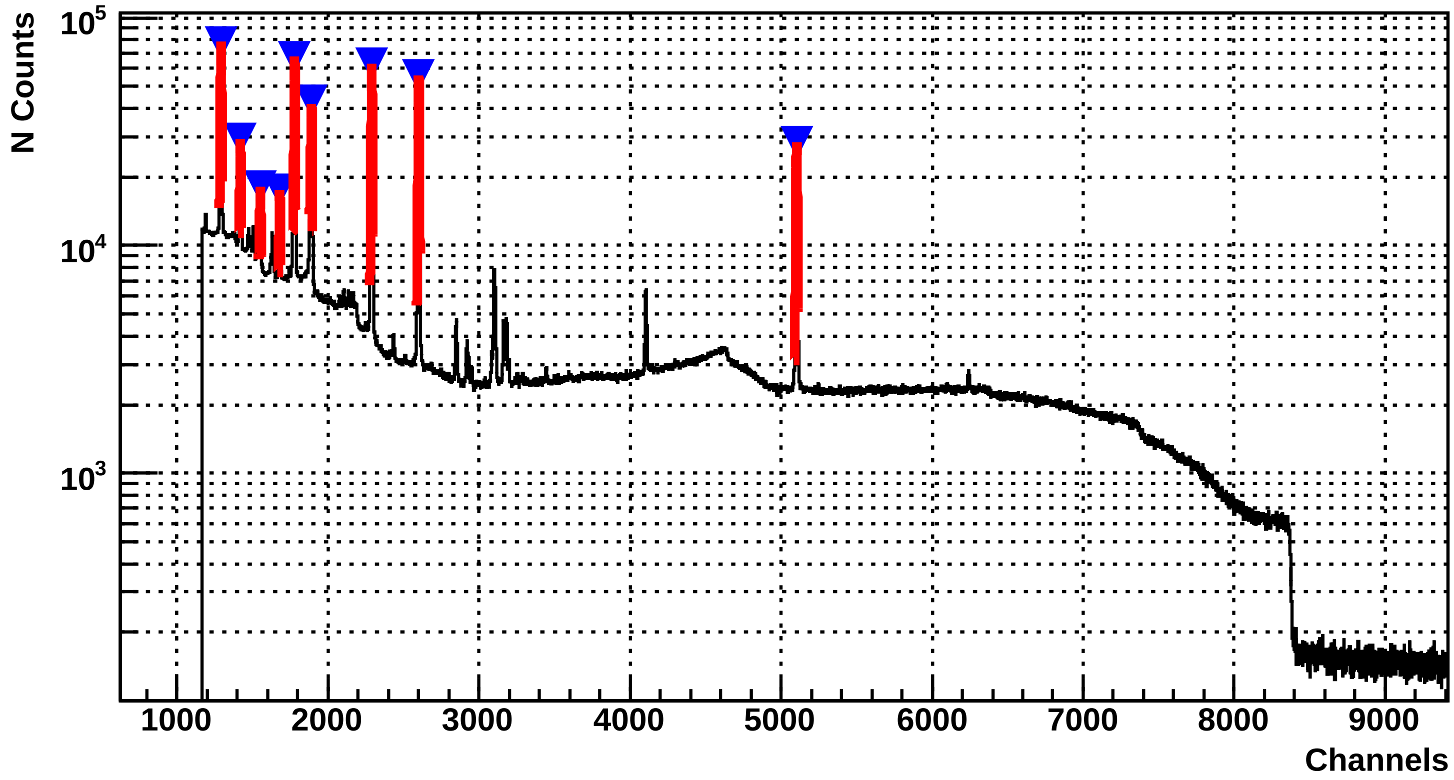
The resonant depolarization (RD) once a day with $\sigma_E < 20$ keV

Compton Backscattering Monitor

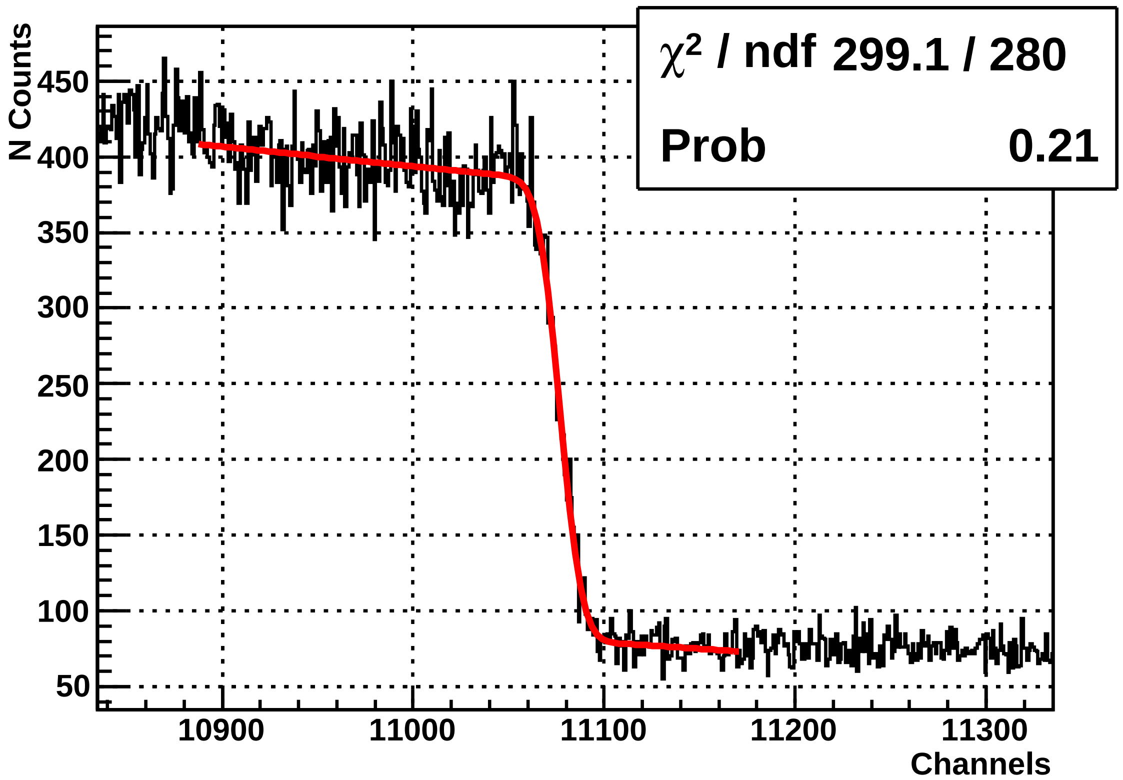
Realized at BESSY-I in 1987



Spectrum of CBS Photons with Calibration Lines

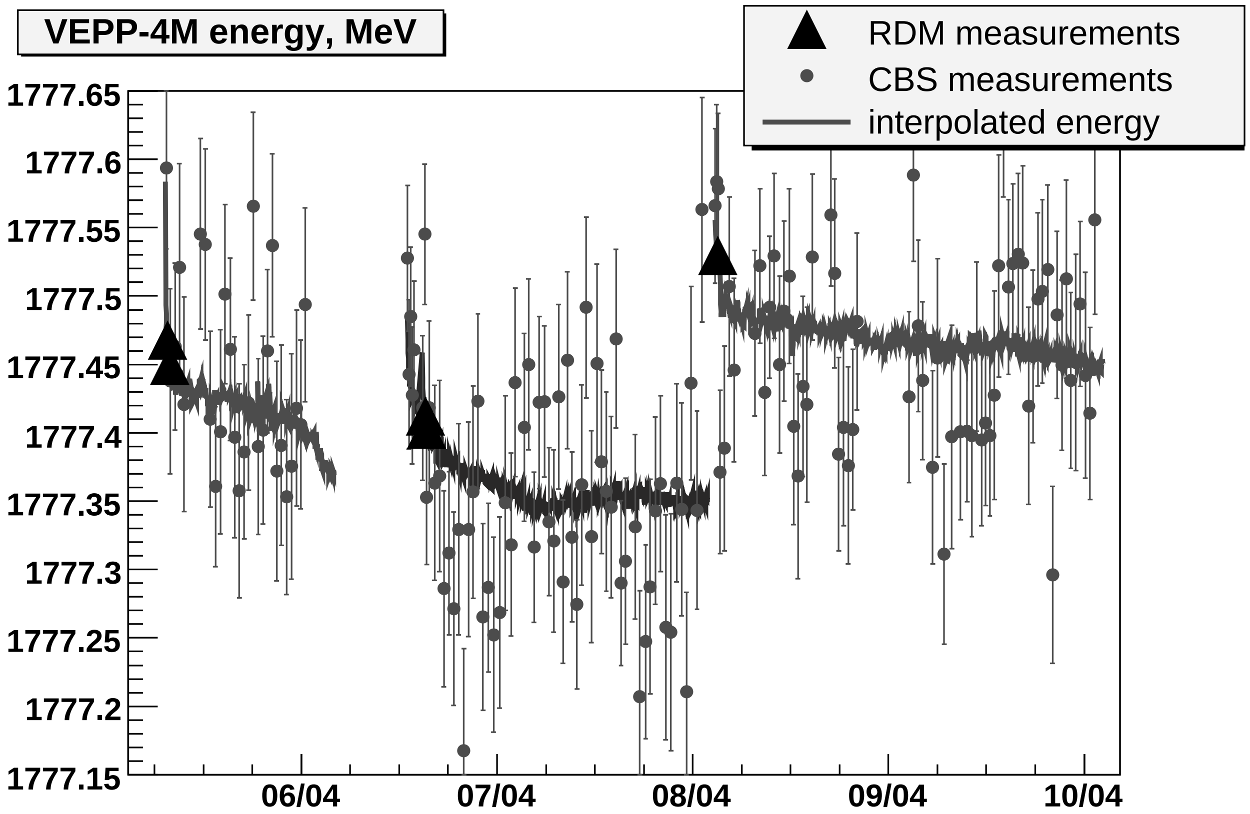


Typical CBS Spectrum Edge at VEPP-4M



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

VEPP-4M Energy Behaviour



During the run, E measured by CBS and from interpolation

Plans

In 2008-2009

- $0.8\ \text{pb}^{-1}$ at J/ψ
- R measurement and search for narrow resonances
  1. Scan of $2.0 < \sqrt{s} < 3.1$ GeV, $\Delta_{\sqrt{s}} = 1$ MeV – $0.25\ \text{pb}^{-1}$
  2. Scan of $3.1 < \sqrt{s} < 4.7$ GeV – $1.5\ \text{pb}^{-1}$
  3. Scan of $4.7 < \sqrt{s} < 8.0$ GeV – 3-4 pb^{-1}

Long-Term after detector upgrade

- $\psi(3770)$ – 5 pb^{-1}, $\sigma(m_D) = 100$ keV
- 10M J/ψ and $\psi(2S)$
- Scan of $8.0 < \sqrt{s} < 11.0$ GeV – 100 pb^{-1} for R and 2γ physics