Recent results from the KEDR Detector

A.E.Blinov (on behalf of the KEDR Collaboration)

BINP, Novosibirsk, Russia

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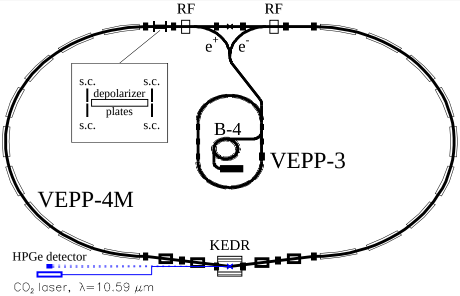
Outline

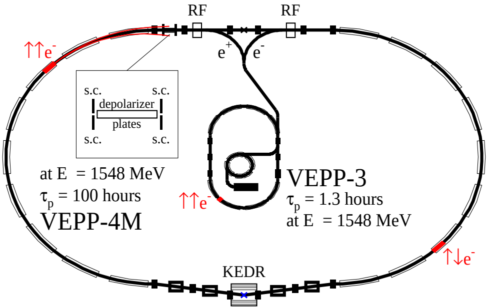
1. Introduction
2. VEPP-4M collider
3. Beam energy determination technique
   - Resonant depolarization method
   - IR-light backscattering
4. KEDR detector
5. $\psi(3770)$ mass , Γ_{total} and Γ_{ee} measurements
6. D mass measurement
7. Search for narrow resonances below J/ψ
8. Conclusions

VEPP–4M collider



Beam energy	$1 \div 6$ GeV
Number of bunches	2×2
Beam current, $E = 1.8$ GeV	2.0 mA
Luminosity, $E = 1.8$ GeV	$1.5 \cdot 10^{30} \frac{1}{cm^2 \cdot s}$

- Resonant depolarization technique:
  Instant measurement accuracy $\simeq 1 \times 10^{-6}$
  Energy interpolation accuracy $(5 \div 15) \times 10^{-6}$ $(10 \div 30$ keV$)$
- Infra-red light Compton backscattering (2005):
  Statistical accuracy $\simeq 5 \times 10^{-5}$ / 30 minutes
  Systematic uncertainty $\simeq 3 \times 10^{-5}$ $(50 \div 70$ keV$)$



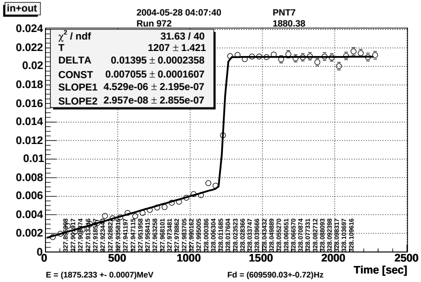
$$\Omega_{spin}/\omega_{rev} = 1 + \gamma \cdot \mu'/\mu_0$$

Touschek (intra-beam scattered) electron pairs are detected with 2×2 scintillation counters (s.c.)

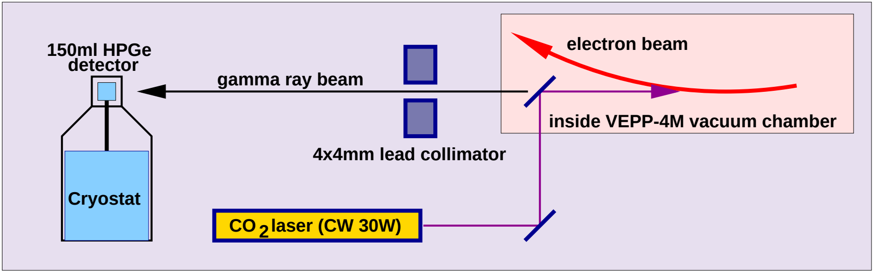
$$\Omega_{spin} \pm \Omega_{dep} = n \cdot \omega_{rev}$$

Scattering rates from unpolarized ↑↓ and polarized ↑↑ beams are compared

$$\Delta = \frac{f_{pol} - f_{unpol}}{f_{pol}}$$



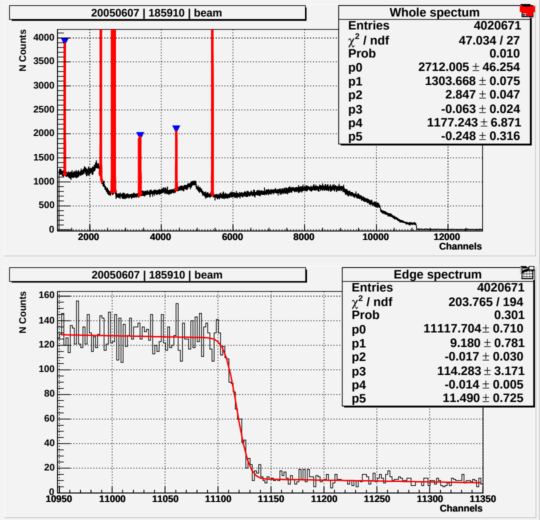
- R. Klein et al., NIM A384 (1997) 293: BESSY–I, 800 MeV
- R. Klein et al., NIM A486 (2002) 545: BESSY–II, 1700 MeV



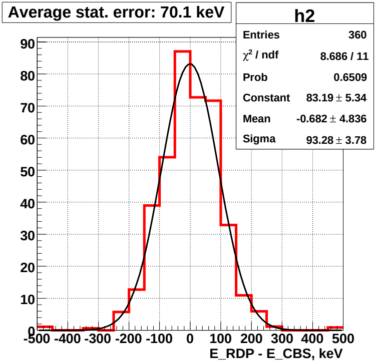
$$\omega'_{max} = \frac{E^2}{E + m^2/4\omega_{laser}}$$

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

Compton backscattering spectrum

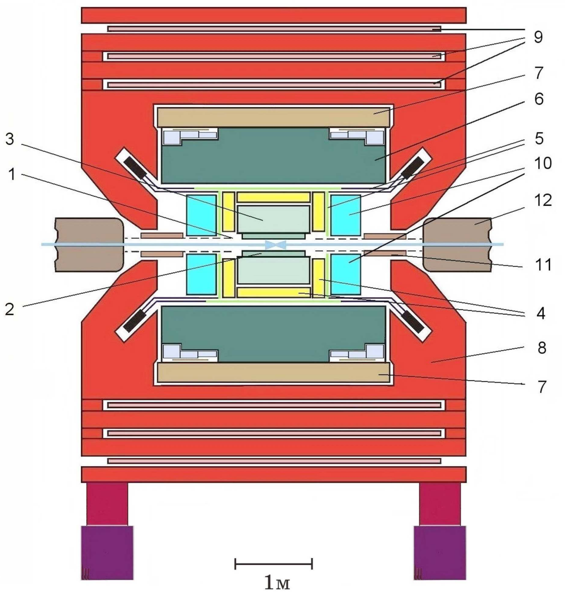


⇐ unlike BESSY–II, only standard isotopes are used for the detector calibration



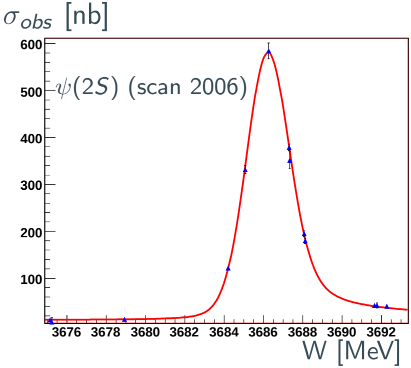
- Final CBS calibration with resonant depolarization ⇑
- Energy determination accuracy: 50÷100 keV (stat), 60 keV (syst)
- Energy spread determination accuracy ≃ 7 % (syst)

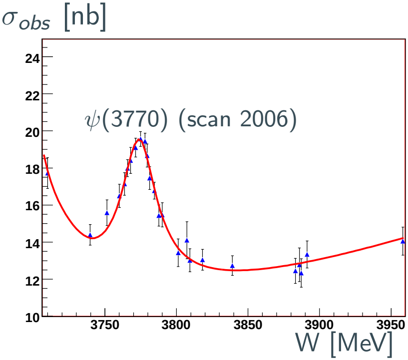
KEDR detector



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

$\psi(3770)$ mass , Γ_{total} and Γ_{ee} measurements





Three scans in region $\psi(2S) - \psi(3770)$.

Scans 2004 $\int \mathcal{L}\, dt \simeq 0.6\ \mathrm{pb}^{-1}$

Scan 2006 $\int \mathcal{L}\, dt \simeq 1.8\ \mathrm{pb}^{-1}$

Parameterization of hadronic cross section

$$\sigma_{fit}(w) = \sigma_{q\bar{q}} + \varepsilon_{\psi(2S)} \cdot \int dw'\, dx\, \sigma_{\psi(2S)}(w')\, \mathscr{F}(x, w') \cdot G(\frac{W-W'}{\sigma_w})$$
$$+\varepsilon_{D\bar{D}} \cdot \int dw'\, dx\, (\sigma_{\psi(3770)}(w') + \sigma^{nonres}_{D\bar{D}}(w'))\, \mathscr{F}(x, w') \cdot G(\frac{W-W'}{\sigma_w})$$

$G(\frac{W-W'}{\sigma_w})$ – Gaussian function, $\mathscr{F}(x, W)$ – radiative correction function:
E.A.Kuraev and V.S.Fadin, Sov.J.Nucl.Phys.41(1985)466.

$$\sigma_{\psi(3770)}(w) = \frac{3\pi}{M^2} \frac{\Gamma_{ee}\Gamma_h}{(W(1-x)-M)^2+\Gamma(W)^2/4}$$

$$\Gamma(w) = \Gamma_{tot} \frac{\frac{(R_0 * p_{D_0}(W))^3}{1+(R_0 * p_{D_0}(W))^2} + \frac{(R_0 * p_{D_\pm}(W))^3}{1+(R_0 * p_{D_\pm}(W))^2}}{\frac{(R_0 * p_{D_0}(M))^3}{1+(R_0 * p_{D_0}(M))^2} + \frac{(R_0 * p_{D_\pm}(M))^3}{1+(R_0 * p_{D_\pm}(M))^2}}$$

Parameters of the fit:

$\sigma_{q\bar{q}}(w)$ – light quarks cross section
$\varepsilon_{\psi(2S)}$ – $\psi(2S)$ efficiency
$\varepsilon_{D\bar{D}}$ – $D\bar{D}$ efficiency
σ_w – at $\psi(2S)$

M – $\psi(3770)$ mass
Γ_{tot} – $\psi(3770)$ width parameter
R_0 – interaction radius

Nonresonant $D\bar{D}$ cross section and interference

$$\sigma^{nonres}_{D\bar{D}}(W) = \sigma^0(W) + \sigma^{\pm}(W)$$

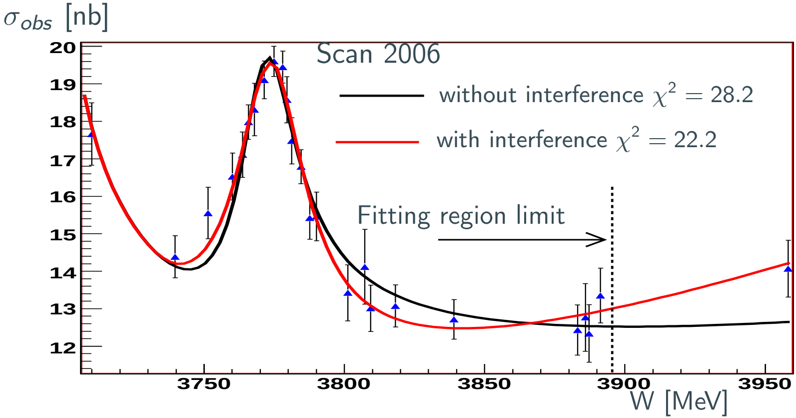
$$\sigma^{0,\pm}(W) = \sigma_{D\bar{D}} \cdot \beta^3_{D^{0,\pm}}$$

In "standard" parameterization of $\sigma_{fit}(w)$ interference between $\psi(3770)$ and nonresonant $D\bar{D}$ production is absent. We tried to include it parameterizing $D\bar{D}$ cross section also as:

$$\sigma_{D\bar{D}}(w) = \int dw'\, dx |A_{\psi(3770)}(w) + A^{nonres}_{D\bar{D}}(w) \cdot e^{i\phi}|^2 \mathscr{F}(x, w') \cdot G(\frac{W-W'}{\sigma_w}),$$

where $|A_{\psi(3770)}(w)|^2 = \sigma_{\psi(3770)}(w)$, $\quad A^{nonres}_{D\bar{D}}(w) = \sqrt{\sigma^{nonres}_{D\bar{D}}(w)}$

Two fits



Black line - fit without intererence (parameterization is identical to one used in MARKI,MARK2,DELCO,BES(2005) experiments):
$\sigma^{nonres}_{D\bar{D}}(3770) = 0.12 \pm 0.03$ nb .

Red line - fit with interference of resonant and nonresonant amplitudes:
$\sigma^{nonres}_{D\bar{D}}(3770) = 0.39 \pm 0.09$ nb, $\quad \phi = 3.4 \pm 0.3$.

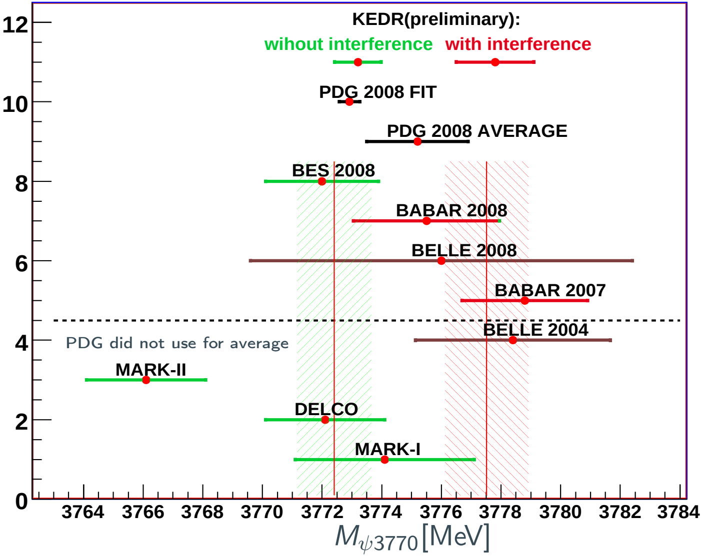
Results

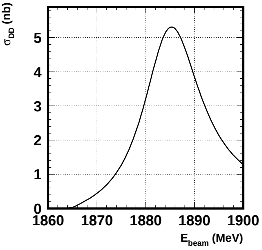
fit without interference			
	$M_{\psi(3770)}$ [MeV]	Γ_{tot} [MeV]	Γ_{ee} eV
2004 year	$3772.5 \pm 1.0 \pm 0.7$	$21.2 \pm 6.0 \pm 1.1$	$256 \pm 37 \pm 40$
2006 year	$3773.4 \pm 0.6 \pm 0.5$	$24.3 \pm 2.4 \pm 1.0$	$315 \pm 28 \pm 25$
	$3773.2 \pm 0.5 \pm 0.6$	$23.9 \pm 2.2 \pm 1.1$	$294 \pm 22 \pm 30$
fit with interference			
2004 year	$3778.6 \pm 1.5 \pm 0.7$	$27.1 \pm 5.5 \pm 1.6$	$367 \pm 50 \pm 40$
2006 year	$3777.0 \pm 1.5 \pm 0.7$	$28.7 \pm 3.7 \pm 2.7$	$276 \pm 40 \pm 22$
	$3777.8 \pm 1.1 \pm 0.7$	$28.2 \pm 3.1 \pm 2.4$	$312 \pm 31 \pm 30$

Comparison with other experiments

Эксперимент	$M_{\psi(3770)}$[MeV]	$\Gamma_{\psi(3770)}$ [MeV]
MARK-I	3774.1 ± 3	28 ± 5
DELCO	3772.1 ± 2	24 ± 5
MARK-II	3766.1 ± 2	24 ± 5
BES-II 2007	-	$28.5 \pm 1.2 \pm 0.2$
BES-II 2008	3772.0 ± 1.9	30.4 ± 8.5
BELLE 2004	$3778.4 \pm 3.0 \pm 1.3$	-
BABAR 2007	$3778.8 \pm 1.9 \pm 0.9$	$23.5 \pm 3.7 \pm 0.9$
BELLE 2008	$3776.0 \pm 5.0 \pm 4.0$	$27 \pm 10 \pm 5$
BABAR 2008	$3775.5 \pm 2.4 \pm 0.5$	-
PDG2008 FIT	3772.92 ± 0.35	27.3 ± 1.0
PDG2008 AVERAGE	3775.2 ± 1.7	27.6 ± 1.0
KEDR (without interference)	$3773.2 \pm 0.5 \pm 0.6$	$23.9 \pm 2.2 \pm 1.1$
KEDR (with interference)	$3777.8 \pm 1.1 \pm 0.7$	$28.2 \pm 3.1 \pm 2.4$

Experiments results for $\psi(3770)$mass





The process $e^+e^- \to \psi(3770) \to D\overline{D}$ is used
One of the D mesons is fully reconstructed

$$D^0 \to K^-\pi^+ \qquad \mathcal{B} = 3.8 \pm 0.1\%$$
$$D^+ \to K^-\pi^+\pi^+ \qquad \mathcal{B} = 9.2 \pm 0.6\%$$

The mass is measured as

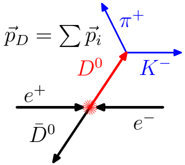
$$M_{\mathrm{bc}} = \sqrt{E_{\mathrm{beam}}^2 - (\sum \vec{p}_i)^2}$$

Near-threshold production $p_D = 260$ MeV $\Rightarrow$

$$\sigma^2(M_D) = \sigma_W^2/4 + (\frac{p_D}{M_D})^2\sigma_{p_D}^2 = \sigma_W^2/4 + 0.02\sigma_{p_D}^2$$

The contribution of momentum resolution is reduced.

$\int \mathcal{L}dt \simeq 900\ \mathrm{nb}^{-1}$. Data accumulated in 2004.

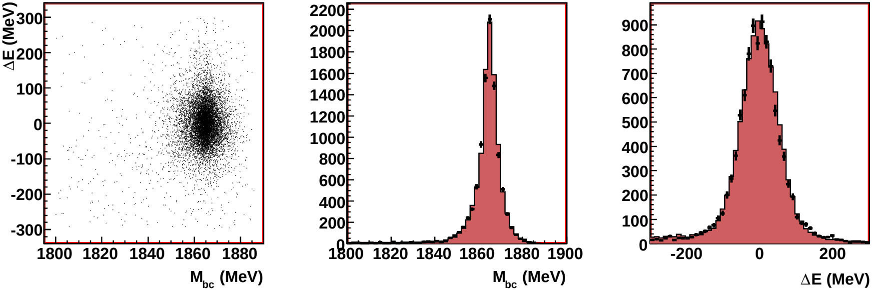


Signal selection variables:

$M_{\rm bc} = \sqrt{E_{beam}^2 - p_D^2}$ and $\Delta E = \sum_i \sqrt{p_i^2 + m_i^2} - E_{beam}$

Signal events: $\Delta E \sim 0$.

Simulation of $D^0 \to K^-\pi^+$:

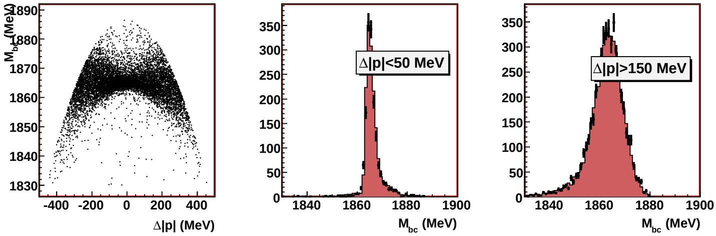


Kinematic fit with $\Delta E = 0$ constraint $\Rightarrow$ better mass resolution, reduced momentum calibration uncertainty.

$\langle \Delta E \rangle = 0$ gives the absolute momentum calibration.

D^0 mass measurement: $D^0 \to K^-\pi^+$

Expected $M_{\rm bc}$ resolution of two-body decay $D^0 \to K^-\pi^+$ depends on decay kinematics (along or transverse to D^0 flight). We use variable $\Delta|p| = |p_K| - |p_\pi|$ to separate events with different $M_{\rm bc}$ resolution.

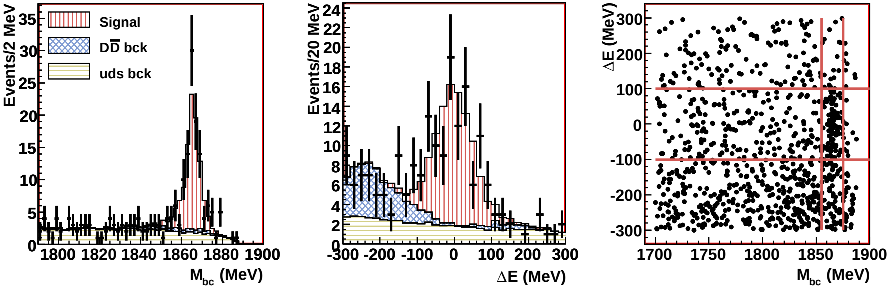


The $\Delta|p|$ was added in minimized inverse log. likelihood function:

$$-2\ln\mathcal{L} = -2\sum_{i=1}^{N_{\rm ev}} \ln p(M_{{\rm bc},i}, \Delta E_i, \Delta|p|_i) \quad \text{(where } p = p_{sig} + p_{bck},\ \int p \equiv 1\text{)}$$

It allows to improve statistical precision of the D^0 mass measurement by a factor of $\simeq 1.5$ (0.55 $\to$ 0.35 MeV).

D^0 mass measurement



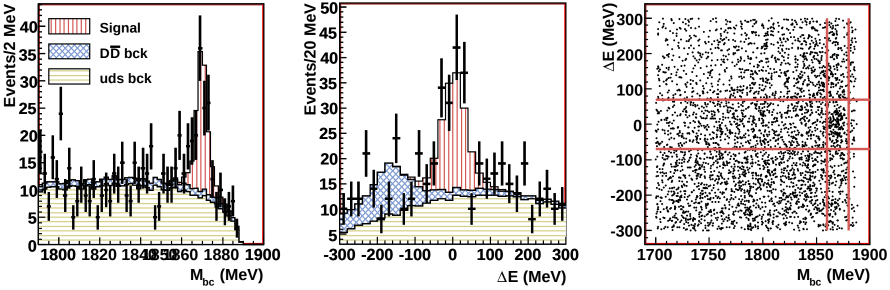
Number of $D^0 \to K^-\pi^+$ events: 98 ± 13.

$M_{D^0} = 1865.30 \pm 0.33 \pm 0.23(\text{syst})\text{MeV}$

Dominant systematic errors:

Radiative corrections ($\sigma(e^+e^- \to D\overline{D})$ uncertainty)	0.16 MeV
Momentum resolution	0.13 MeV
Signal PDF shape	0.07 MeV
Background PDF shape	0.05 MeV
Absolute momentum calibration	0.04 MeV

$D^{\pm}$ mass measurement



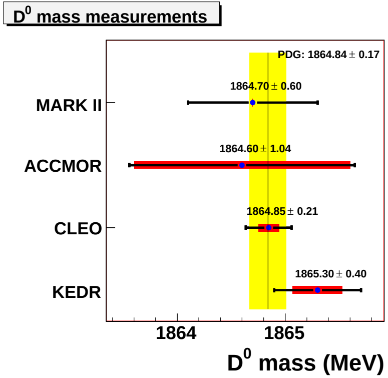
Number of events $D^+ \to K^-\pi^+\pi^+$: 110 ± 15.

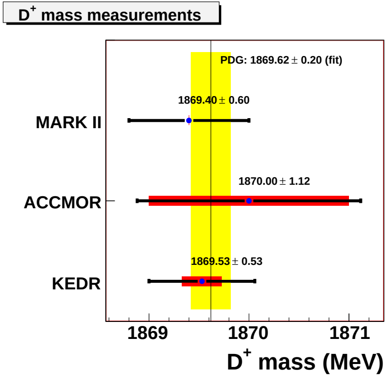
$M_{D^{\pm}} = 1869.53 \pm 0.49 \pm 0.20(\text{syst})\text{MeV}$

Dominant systematic errors:

Radiative corrections ($\sigma(e^+e^- \to D\overline{D})$ uncertainty)	0.11 MeV
Momentum resolution	0.10 MeV
Signal PDF shape	0.05 MeV
Background PDF shape	0.11 MeV
Absolute momentum calibration	0.04 MeV

D mass measurement: comparison with other results





PDG average is dominated by CLEO [PRL 98 (2007) 092002] and D^0-D^+ mass difference.

In W region between 1.4 GeV and $M_{J/\psi}$ no limit on narrow resonances in e^+e^- annihilation cross section was available.
A region from 1.85 GeV to 3.1 GeV has been scanned by KEDR with an E_{beam} step $\simeq (0.7-1.0)\ MeV$.
$\int \mathcal{L}dt \simeq 280$ nb^{-1} is collected.
The data are accumulated in 2009 and the result is very preliminary.

Event selection

Three sets of event selection cuts with $\varepsilon_{J/\psi\to hadr}$=0.43-0.63 are used. The one with highest ε:

- $\geq$2 tracks from event vertex
- $\geq$1 "good" vertex tracks (with cluster in barrel calorimeter)
- there is vertex track acoplanar to "good" one ($\Delta\phi$>0.15 rad)
- aplanarity: sum of momenta transverse to "event plane"$> 0.1 \cdot E_{beam}$
- $\leq$3 hits in Muon Chambers
- $|P_z^{event}/E^{event}| < 0.5$

Parameterization of resonance cross section

$$\sigma_{hadr}(w) = \sigma_{q\bar{q}} + \varepsilon_{hadr} \cdot \int dw'\, dx\, \sigma_{R\to hadr}(w')\, \mathscr{F}(x, w') \cdot G(\tfrac{W-W'}{\sigma_w}),$$

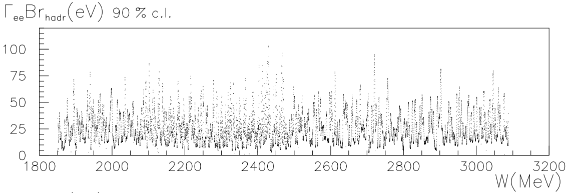
where

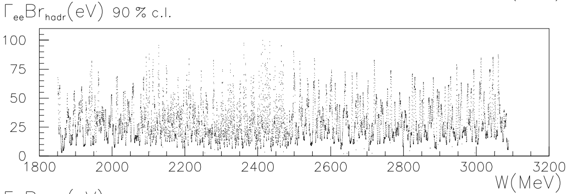
$$\sigma_{R\to hadr}(w) = \frac{4\pi\Gamma^R_{ee}\cdot Br(R\to hadr)\cdot\delta(w-M_R)}{M_R^2}$$

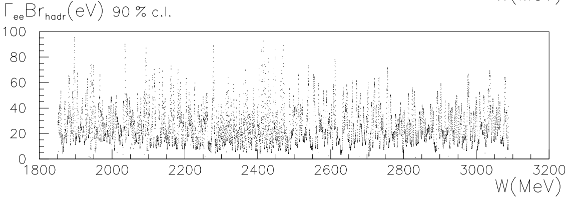
With the $\sigma_{hadr}(w)$ a likelihood fits were done in $M_R \pm 5 MeV$ region with 0.1 MeV M_R steps to get a best fit and 90 % upper limit for $\Gamma^R_{ee} \cdot Br(R \to hadr)$.

For each set of event selection cuts ε_{hadr} was estimated from J/ψ pass in the beginning of the scan, using known $\Gamma^{J/\psi}_{ee} \cdot Br(J/\psi \to hadr)$=4.9 keV.

Fit results


$\Gamma_{ee}Br_{hadr}(eV)$ 90 % c.l.
0
25
50
75
100
1800
2000
2200
2400
2600
2800
3000
3200
W(MeV)


$\Gamma_{ee}Br_{hadr}(eV)$ 90 % c.l.
0
25
50
75
100
1800
2000
2200
2400
2600
2800
3000
3200
W(MeV)


$\Gamma_{ee}Br_{hadr}(eV)$ 90 % c.l.
0
20
40
60
80
100
1800
2000
2200
2400
2600
2800
3000
3200
W(MeV)

Conclusions: Limit on narrow resonances below J/ψ.

All three event selection yield 90 % upper limit for $\Gamma^R_{ee} \cdot Br(R \to hadr) \simeq 100eV$, assuming $\varepsilon_{hadr} = \varepsilon_{J/\psi \to hadr}$, however:

- $\varepsilon_{J/\psi \to hadr} / \varepsilon_{e^+e^- \to hadr} \simeq 1.1$
- $\varepsilon_{e^+e^- \to hadr}(3.1GeV) / \varepsilon_{e^+e^- \to hadr}(1.9GeV) \simeq 1.2$
- variation of σ_W could further increase the limit

therefore, combining all the factors we set a limit for

$\Gamma^R_{ee} \cdot Br(R \to hadr) < 150eV$

in W range between 1.85 GeV and J/ψ.

Conclusion

- The parameters of $\psi(3770)$ are measured using the data collected by KEDR detector at VEPP-4M collider in 2004 and 2006:
- Fit without interference:
  - $M_{\psi(3770)} = 3773.2 \pm 0.5 \pm 0.6$ MeV
  - $\Gamma_{total} = 23.9 \pm 2.2 \pm 1.1$ MeV
  - $\Gamma_{ee} = 294 \pm 22 \pm 30$ eV
- Fit with interference:
  - $M_{\psi(3770)} = 3777.8 \pm 1.1 \pm 0.7$ MeV
  - $\Gamma_{total} = 28.2 \pm 3.1 \pm 2.4$ MeV
  - $\Gamma_{ee} = 312 \pm 31 \pm 30$ eV
  - Interference angle is about π

Conclusion

- The masses of D^0 and D^+ mesons are measured using the data collected by KEDR detector at VEPP-4M collider in 2004. [arXiv:0909.5545 (submitted to PLB)]
- The values of the masses are:
  - $M_{D^0} = 1865.30 \pm 0.33 \pm 0.23$ MeV
  - $M_{D^\pm} = 1869.53 \pm 0.49 \pm 0.20$ MeV
- The D^0 mass is consistent with the more precise CLEO measurement, obtained with the different technique ($D^0 \to K_S^0 \phi$).
- The measurement of the $D^\pm$ mass is the most precise direct one.

The main systematic uncertainties for $\psi(3770)$ mass (fit without interference) in scan 2006

- Conservative estimates of $\psi(3770)$ mass error

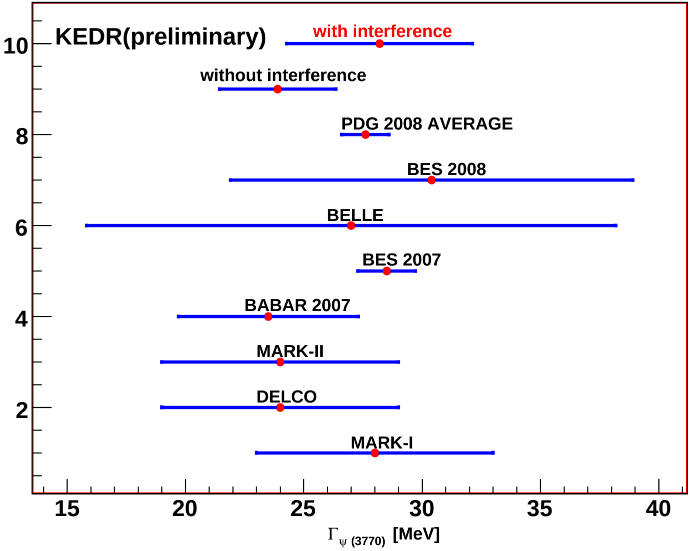
Detection efficiency variations	: 0.4 MeV
Including background from G(3943) resonance	: 0.3 MeV
Luminosity measurement instability	: 0.2 MeV
Fitting form (R_0 variations)	: 0.1 MeV
Fitting energy limit variations	: 0.1 MeV
Absolute energy determination	: <0.1 MeV
Sum in quadrature	: 0.57 MeV

The main systematic uncertainties for $\psi(3770)$ mass (fit with interference) in scan 2006

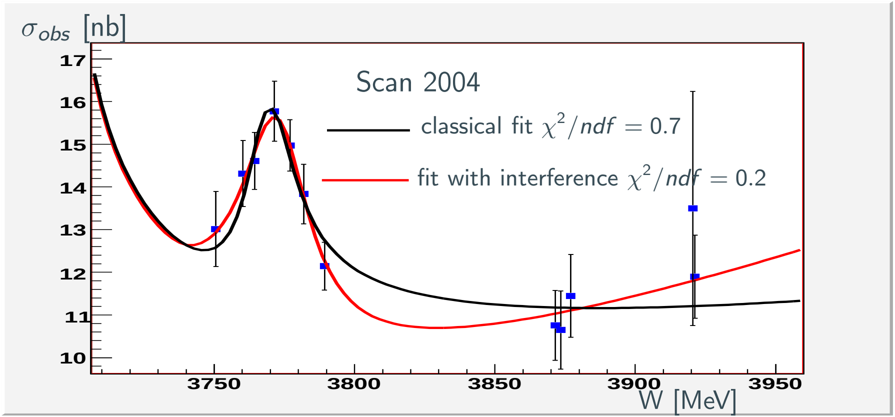
- Conservative estimates $\psi(3770)$ mass error

Fitting form (R_0 variations)	: 0.5 MeV
Including background from G(3943) resonance	: 0.3 MeV
Detection efficiency variations	: 0.3 MeV
Luminosity measurement instability	: 0.2 MeV
Fitting energy limit variations	: 0.1 MeV
Absolute energy determination	: <0.1 MeV
Sum in quadrature	: 0.7 MeV

Experiments results Γ_{tot}



Scan 2004



Fit without interference(black line)
Nonresonant $\sigma_{D\bar{D}} = 0.189 \pm 0.086$ nb.

Fit with interference. (red line).
Nonresonant $\sigma_{D\bar{D}} = 0.368 \pm 0.203$ nb, $\quad \phi = 2.583 \pm 0.845$