# *Recent results from the KEDR detector*

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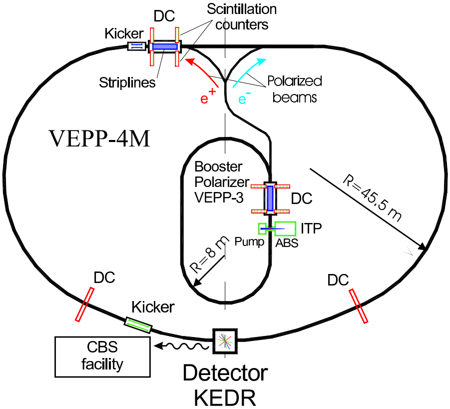
Outline

- VEPP-4M collider and KEDR detector
- Physical program
- High-precision measurement of $J/\psi$ and $\psi(2S)$ masses
- Results for $\Gamma_{ee}(J/\psi) \cdot \mathcal{B}(J/\psi \to e^+e^-)$ and $\Gamma_{ee}(J/\psi) \cdot \mathcal{B}(J/\psi \to \mu^+\mu^-)$
- Preliminary results for $\Gamma_{ee}(\psi(2S)) \cdot \mathcal{B}(\psi(2S) \to hadrons)$
- R measurement and search for narrow resonances below $J/\psi$
- Conclusions and prospects

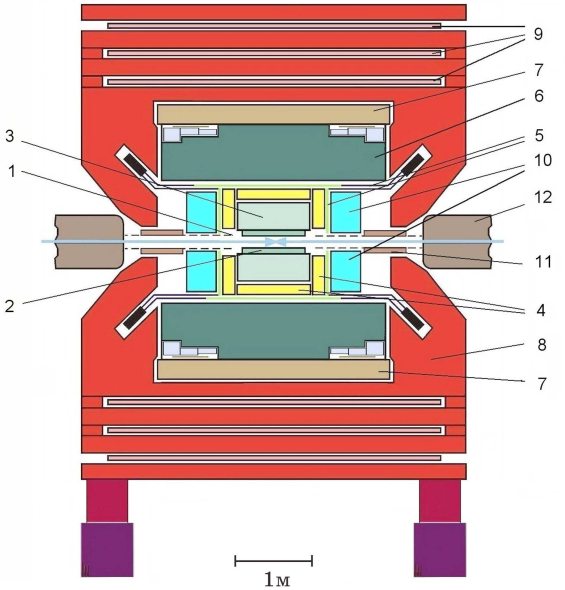
# VEPP–4M collider




| | |
|---|---|
| Beam energy | $1 \div 5.5$ GeV |
| Number of bunches | $2 \times 2$ |
| 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$)$

# *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
13. Electron tagging system (is not shown here)

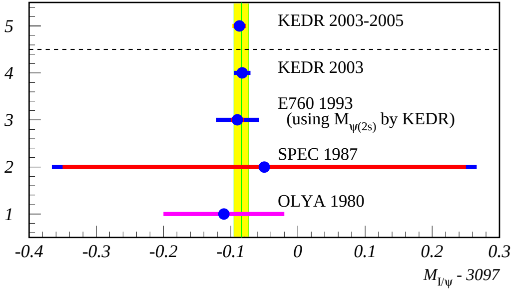
# *Physical program*

- High-precision measurement of $J/\psi, \psi(2S), \psi(3770), D^0, D^{\pm}, \tau,$ $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S), \Upsilon(4S)$ masses
- Leptonic widths measurement for $\psi$ and $\Upsilon$
- $J/\psi$ and $\psi(2S)$ radiative transitions ($J/\psi \to \gamma\eta_c, \psi(2S) \to \gamma\chi_c$, ...)
- $R$ measurement $W = 2 \div 10$ GeV
- $\gamma\gamma$ physics

# $J/\psi$ mass measurement

## $J/\psi$ MASS

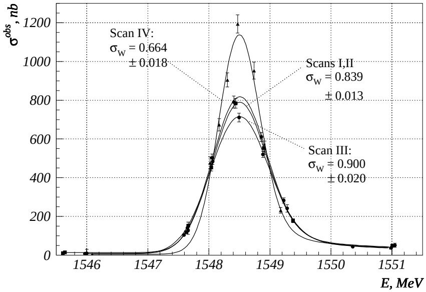
| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|---|
| **3096.916±0.011 OUR AVERAGE** | | | | |
| 3096.917±0.010±0.007 | | AULCHENKO 03 | KEDR | $e^+e^- \to$ hadrons |
| 3096.89 ±0.09 | 502 | [1] ARTAMONOV 00 | OLYA | $e^+e^- \to$ hadrons |
| 3096.91 ±0.03 ±0.01 | | [2] ARMSTRONG 93B | E760 | $\overline{p}p \to e^+e^-$ |
| 3096.95 ±0.1 ±0.3 | 193 | BAGLIN 87 | SPEC | $\overline{p}p \to e^+e^-X$ |



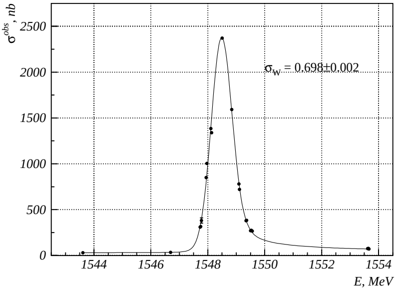

Four PDG records on $J/\psi$ mass and this work result. Red cores of error bars represent systematic uncertainties.

All data are in good agreement, we use one additional scan to confirm the result published in [PL B573(2003)632003].

# $J/\psi$ mass measurement




$J/\psi$ scans of 2002 $\left(\int \mathcal{L}dt \simeq 50\ \text{nb}^{-1}\right)$.




$J/\psi$ scan 2005 $\left(\int \mathcal{L}dt \simeq 230\ \text{nb}^{-1}\right)$.

Correction to 2002 data:

- add $\delta M = 3.6 \pm 2.5$ keV for $\psi$-function chromaticity (was not applied earlier).

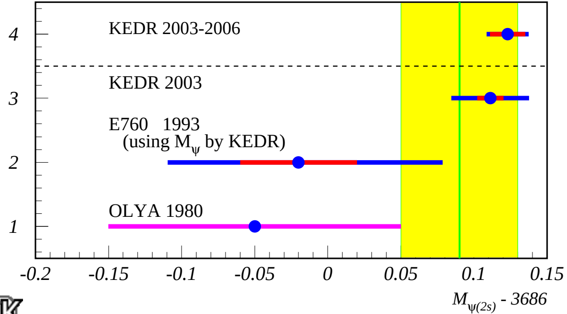
$$M_{J/\psi}^{2002} = 3096.921 \pm 0.010 \pm 0.008\,\text{MeV}$$

$$M_{J/\psi}^{2005} = 3096.903 \pm 0.002 \pm 0.010\,\text{MeV}$$

$$M_{J/\psi} = 3096.913 \pm 0.006 \pm 0.009\ \ \text{MeV}$$

## $\psi(2S)$ MASS

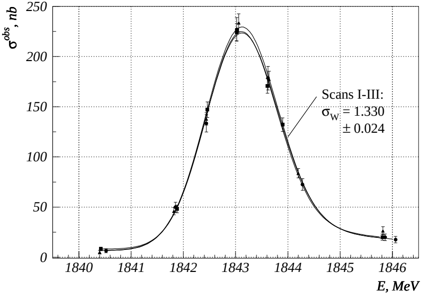
| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|---|---|---|---|---|
| **3686.09 ±0.04 OUR FIT** Error includes scale factor of 1.6. | | | | |
| **3686.093±0.034 OUR AVERAGE** Error includes scale factor of 1.4. See the ideogram below. | | | | |
| 3686.111±0.025±0.009 | | AULCHENKO 03 | KEDR | $e^+e^- \to$ hadrons |
| 3685.95 ±0.10 | 413 | [1] ARTAMONOV 00 | OLYA | $e^+e^- \to$ hadrons |
| 3685.98 ±0.09 ±0.04 | | [2] ARMSTRONG 93B | E760 | $\overline{p}p \to e^+e^-$ |

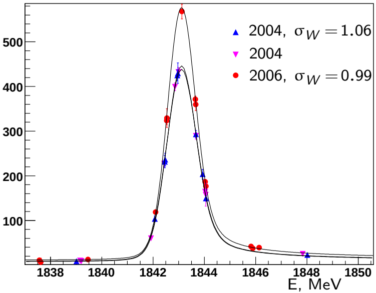



Three PDG records on $\psi(2S)$ mass and this work result. Red cores of error bars represent systematic uncertainties.

# $\psi(2S)$ *mass measurement*

We used three additional scans to confirm the published result and improve $\psi(2S)$ mass accuracy to that of $J/\psi$ mass:




$\psi(2S)$ scans of 2002$\left(\int \mathcal{L}dt \simeq 75\ \text{nb}^{-1}\right)$. Scans 2004, 2006 $\left(\int \mathcal{L}dt \simeq 500\ \text{nb}^{-1}\right)$.

$$M^{2002}_{\psi(2S)} = 3686.110 \pm 0.025 \pm 0.013\,\text{MeV}$$

$$M^{2004}_{\psi(2S)} = 3686.128 \pm 0.010 \pm 0.012\,\text{MeV}$$

$$M^{2006}_{\psi(2S)} = 3686.120 \pm 0.011 \pm 0.012\,\text{MeV}$$

$$M_{\psi(2S)} = 3686.123 \pm 0.008 \pm 0.012\,\text{MeV}$$

# *Current results for D mesons and τ lepton masses*

- $m_{\tau}^{KEDR} = 1776.69^{+0.17}_{-0.19} \pm 0.15$ MeV    published in NP B189(2009)

  The result is still preliminary, detector related uncertainties dominate in the systematic error but it is currently most precise.

- $m_{D^{\pm}} = 1869.53 \pm 0.49 \pm 0.20$ MeV
  $m_{D^{0}} = 1865.30 \pm 0.33 \pm 0.23$ MeV    published in PLB 686 (2010)

  The $D^0$ mass value is consistent with the more precise measurement of the CLEO Collaboration , while that of the D+ mass is presently the most precise direct determination. Plan to collect more data after detector upgrading.

# $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ *for* $J/\psi$ *theory*

Cross section $e^+e^- \to e^+e^-$ in soft photon approximation

$$\left(\frac{d\sigma}{d\Omega}\right)_{th} = \frac{1}{M^2}\left\{\frac{9}{4}\frac{\Gamma^2_{e^+e^-}}{\Gamma M}\left(1+\delta_{sf}\right)\left(1+\cos^2\theta\right)\mathrm{Im}\,\mathcal{F} - \frac{3\alpha}{2}\frac{\Gamma_{e^+e^-}}{M}\left[\left(1+\cos^2\theta\right) - \frac{(1+\cos^2\theta)^2}{(1-\cos\theta)}\right]\mathrm{Re}\,\mathcal{F}\right\} + \left(\frac{d\sigma}{d\Omega}\right)_{QED}$$

$$\mathcal{F} = \frac{\pi\beta}{\sin\pi\beta}\left(\frac{M/2}{-W+M-i\Gamma/2}\right)^{1-\beta}, \quad \beta = \frac{4\alpha}{\pi}\left(\ln\frac{W}{m_e} - \frac{1}{2}\right)$$

Asimov at el. JETP Lett.21,(1975),

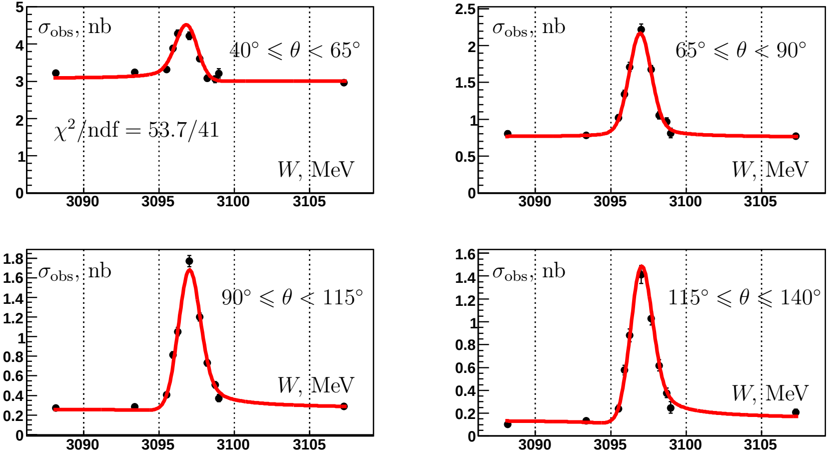
Todyshev, 2009, arXiv:0902.4100

where a correction $\delta_{sf}$ follows from the structure function approach of E. A. Kuraev and V. S. Fadin, Sov. J. Nucl. Phys. **41**, 466 (1985).

Taking into account c.m.s. energy spread $\sigma_W$:

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

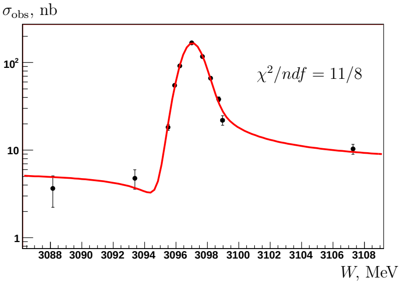
# *Measurement of* $\Gamma_{e^+e^-}\Gamma_{e^+e^-}/\Gamma$ *for* $J/\psi$




Fits to experimental data for $e^+e^- \to e^+e^-$.

# Measurement of $\Gamma_{e^+e^-}\Gamma_{\mu^+\mu^-}/\Gamma$ for $J/\psi$

$$\left(\frac{d\sigma}{d\Omega}\right)^{ee\to\mu\mu} = \frac{3}{4M^2}\left(1+\delta_{sf}\right)\left(1+\cos^2\theta\right) \times$$
$$\left\{\frac{3\Gamma_{ee}\Gamma_{\mu\mu}}{\Gamma M}\mathrm{Im}\mathcal{F} - \frac{2\alpha\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}}{M}\mathrm{Re}\frac{\mathcal{F}}{1-\Pi_0}\right\} + \left(\frac{d\sigma}{d\Omega}\right)^{\mu\mu}_{QED},$$

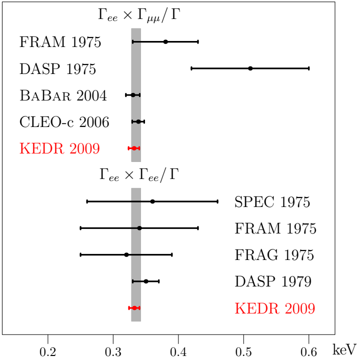


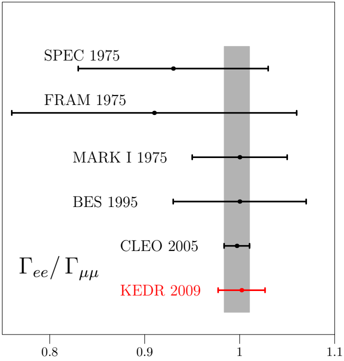

Fit to experimental data for $e^+e^- \to \mu^+\mu^-$.

# *Results for* $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}(J/\psi\to e^+e^-)$ *and* $\Gamma_{ee}(J/\psi)\cdot\mathcal{B}(J/\psi\to\mu^+\mu^-)$

$$\Gamma_{ee}\times\Gamma_{ee}/\Gamma = 0.3323\pm0.0064\pm0.0048\text{keV}$$
$$\Gamma_{ee}\times\Gamma_{\mu\mu}/\Gamma = 0.3318\pm0.0052\pm0.0063\text{keV}$$
$$\Gamma_{ee}/\Gamma_{\mu\mu} = 1.002\pm0.021\pm0.013$$

V. V. Anashin, et al., Phys. Lett. B **685**, 134 (2010), **arXiv:0912.1082**.



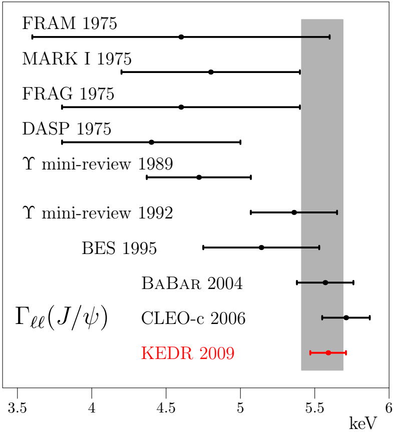




$\Gamma_{ee}\times\Gamma_{ee}/\Gamma$ and $\Gamma_{ee}\times\Gamma_{\mu\mu}/\Gamma$

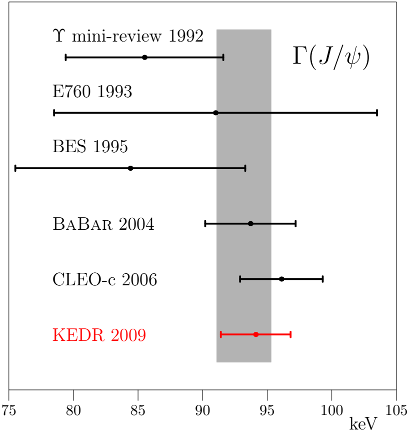
$\Gamma_{ee}/\Gamma_{\mu\mu}$

# Results for $\Gamma_{\ell\ell}(J/\psi)$ and $\Gamma(J/\psi)$

$$\Gamma_{\ell\ell}(J/\psi) = 5.59 \pm 0.12 \text{ keV}$$
$$\Gamma(J/\psi) = 94.1 \pm 2.1 \text{ keV}$$




$\Gamma_{\ell\ell}(J/\psi)$

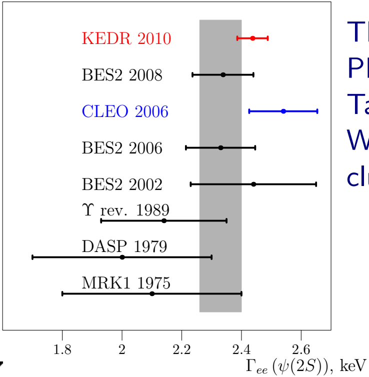



$\Gamma(J/\psi)$

# *Preliminary results for* $\Gamma_{e^+e^-}(\psi(2S)) \cdot \mathcal{B}(\psi(2S) \to hadrons)$

$$\Gamma_{ee} \times \mathcal{B}_{hadr.}(2004) = 2.392 \pm 0.019 \pm 0.045\,\text{keV}$$
$$\Gamma_{ee} \times \mathcal{B}_{hadr.}(2006) = 2.374 \pm 0.024 \pm 0.052\,\text{keV}$$

$$\Gamma_{ee} \times \mathcal{B}_{hadr.} = 2.385 \pm 0.015 \pm 0.048\,\text{keV}\ (preliminary!)$$




There is only **MRK I** result for $\Gamma_{ee} \times \mathcal{B}_{hadr.}$ in PDG.
Taking into account $\mathcal{B}^{PDG}_{hadr.} = 0.9785 \pm 0.0013$
We compare $\Gamma_{ee}$ with others experiments included in PDG and CLEO result from e-print.

$$\Gamma_{ee} = 2.437 \pm 0.051\ \text{keV}\ (preliminary!)$$

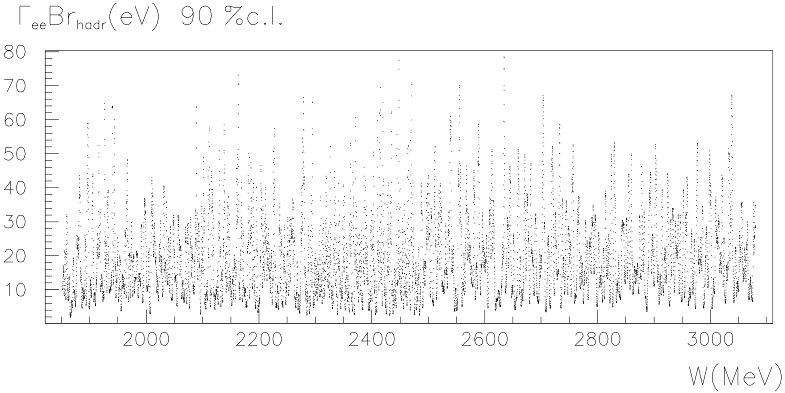
# $R$ *measurement below* $J/\psi$

- A region from 1.85 GeV to 3.1 GeV has been scanned by KEDR in 2009-2010 for R measurement. $\int \mathcal{L}dt \simeq 0.9$ pb$^{-1}$ are accumulated. Error $4-6\%$ is expected.

- $\int \mathcal{L}dt \simeq 0.6$ pb$^{-1}$ with energy beam step $E_{beam}^{step} = 50\ MeV$ and $\int \mathcal{L}dt \simeq 0.3$ pb$^{-1}$ is collected during scan with energy beam step $E_{beam}^{step} = 0.7 \div 0.95\ MeV$($\sim 10^3$ points)

- 90 % upper limit for $\Gamma_{ee}^{R} \cdot \mathcal{B}(R \to hadr) \simeq 500\ eV$ in this energy region (experiments at the ADONE,Frascati )

# *Search for narrow resonances below J/ψ*




90 % upper limit for $\Gamma_{ee}^{R} \cdot \mathcal{B}(R \to hadr) \simeq 120\ eV$ (preliminary)
in W range between 1.85 GeV and $J/\psi$.

# *Conclusions and prospects*

- High-precision measurement of $J/\psi, \psi(2S), D^0, D^{\pm}, \tau$ lepton masses were performed.
- The products of the electron width of the $J/\psi$ meson and the branching fraction of its decays to the lepton pairs were measured.
- Limit on narrow resonances below $J/\psi$ has been obtained.
- Statistics for R measurement in energy region from 1.85 GeV to 3.1 GeV were collected

Plans

- R measurement above $J/\psi$
- Collect $\int \mathcal{L}dt \simeq 200 \div 300$ pb$^{-1}$ for $\gamma\gamma$ physics
- $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S), \Upsilon(4S)$ mass measurement.

Next reports from KEDR about measurements $\psi(3770)$ parameters

and $\mathcal{B}_{J/\psi\rightarrow\gamma\eta_c}$

BACKUP

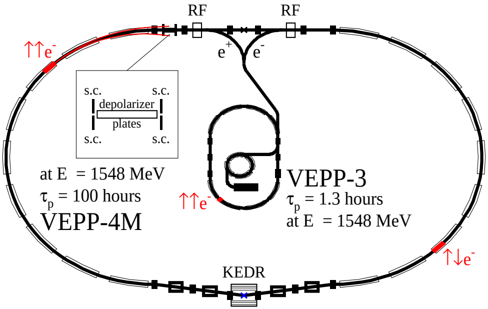
# *Limit on narrow resonances below $J/\psi$.*

90 % upper limit for $\Gamma_{ee}^{R} \cdot Br(R \to hadr) \simeq 80eV$ is obtained, assuming $\varepsilon_{hadr} = \varepsilon_{J/\psi \to hadr}$. However:

- $\varepsilon_{J/\psi \to hadr} / \varepsilon_{e^+e^- \to hadr} \simeq 1.15$
- $\varepsilon_{e^+e^- \to hadr}(3.1GeV) / \varepsilon_{e^+e^- \to hadr}(1.9GeV) \simeq 1.2$
- variation of $\sigma_w$ could further increase the limit

Therefore, combining all the factors we set a 90 % c.l. for

$\Gamma_{ee}^{R} \cdot Br(R \to hadr) < 120eV$ in W range between 1.85 GeV and $J/\psi$.



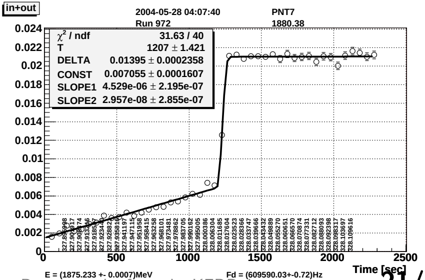

$$\Omega_{spin}/\omega_{rev} = 1+\gamma\cdot\mu'/\mu_0$$

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

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

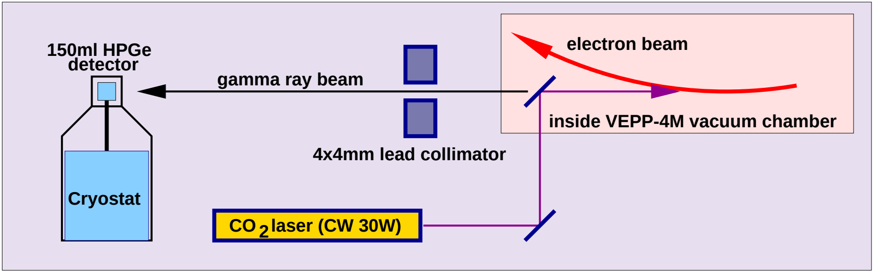
Scattering rates from unpolarized ↑↓ and polarized ↑↑ beams are compared

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



# *Energy monitoring using IR-light Compton backscattering*

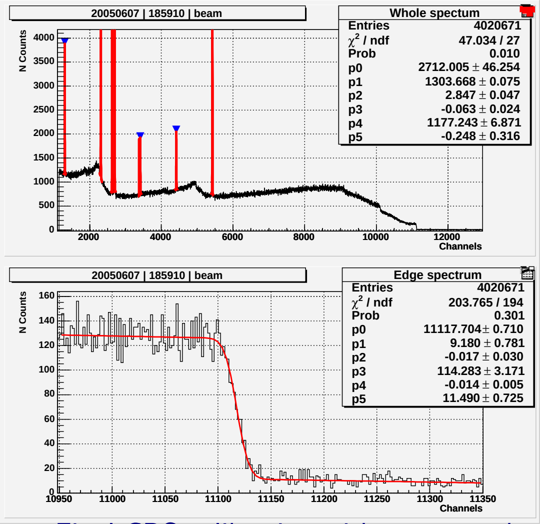
- R. Klein et al., NIM A384 (1997) 293: BESSY–I, 800 MeV
- R. Klein et al., NIM A486 (2002) 545: BESSY–II, 1700 MeV



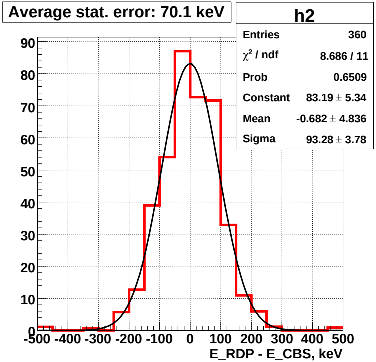

$$\omega'_{max} = \frac{E^2}{E + m^2/4\omega_{laser}}$$

- $CO_2$ – 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 $\simeq$ 7 % (syst)

# *Systematic uncertainties calculation*

Mass weighting recipe keeping tracks of the statistical and systematic uncertainties separately:

$$M = \sum w_i \cdot M_i \qquad \sigma^2_{stat} = \sum w_i^2 \cdot \sigma^2_{stat,i}$$
$$\sigma^2_{syst} = \sum w_i^2 \cdot (\sigma^2_{syst,i} - \sigma^2_{syst,0}) + \sigma^2_{syst,0}$$
$$w_i \propto 1/(\sigma^2_{stat,i} + \sigma^2_{syst,i} - \sigma^2_{syst,0})$$

where weights $w_i$ take into account statistical errors and uncorrelated parts of systematic error, $\sigma_{syst,0}$ is a common part of systematic uncertainties.

# *Systematic uncertainties in the $J/\psi$ mass*

***Table:*** Systematic uncertainties in the $J/\psi$ mass (keV) defined in [PLB573(2003)632003].

| *Uncertainty source* | 2002 | 2005 | common |
|---|---|---|---|
| Energy spread variation | 3.0 | 1. | 0.7 |
| Energy assignment | 3.8 | 11. | 3.0 |
| Beam misalignment in the I.P. | 1.8 | 1.3 | 1.2 |
| $e^+$-, $e^-$-energy difference | $<2.0$ | 6.0 | 2.0 |
| Symmetric $dL/dE$ shape distortion | $<1.5$ | $<1.5$ | 0.5 |
| Asymmetric $dL/dE$ shape distortion | 3.2 | 3.5 | 2.0 |
| Beam potential | 1.0 | 1.5 | 1.0 |
| Single energy calibration | 0.6 | 0.5 | 0.5 |
| Detection efficiency instability | 2.3 | 2.3 | |
| Luminosity measurements | 2.2 | 2.4 | |
| Interference in the hadronic channel | 1.3 | 1.1 | 1.0 |
| Residual machine background | $<1.0$ | $<0.3$ | |
| *Sum in quadrature* | $\approx 7.6$ | $\approx 13.8$ | $\approx 4.6$ |

# *Systematic uncertainties in the* $\psi(2S)$ *mass*

***Table:*** Systematic uncertainties in the $\psi(2S)$ mass (keV), defined in [PL B573(2003)632003].

| *Error source* | 2002 | 2004 | 2006 | common |
|---|---|---|---|---|
| Energy spread variation | 2.0 | 1.8 | 1.7 | 0.7 |
| Energy assignment | 4.3 | 6.5 | 6.5 | 4.0 |
| Beam misalignment in the I.P. | 5.1 | 4.0 | 4.0 | 3.7 |
| $e^+$-, $e^-$-energy difference | 9.0 | 7.0 | 7.0 | 6.0 |
| Symmetric $dL/dE$ shape distortion | $<2.0$ | $<1.8$ | $<1.7$ | $<1.2$ |
| Asymmetric $dL/dE$ shape distortion | 3.5 | 3.1 | 2.9 | 2.5 |
| Beam potential | 1.0 | 1.2 | 1.2 | 1.0 |
| Single energy calibration | 0.8 | 0.7 | 0.7 | 0.5 |
| Detection efficiency instability | 2.0 | 2.4 | 2.4 | |
| Luminosity measurements | 3.0 | 3.0 | 3.0 | |
| Interference in the hadronic channel | 0.8 | 0.7 | 0.6 | 0.6 |
| Residual machine background | $<1.0$ | $<0.5$ | $<0.5$ | |
| *Sum in quadrature* | $\approx 12.7$ | $\approx 11.9$ | $\approx 11.8$ | $\approx 8.7$ |