Измерение вероятности распада $J/\psi \to \gamma\eta_C$ и параметров η_C мезона на детекторе КЕДР.

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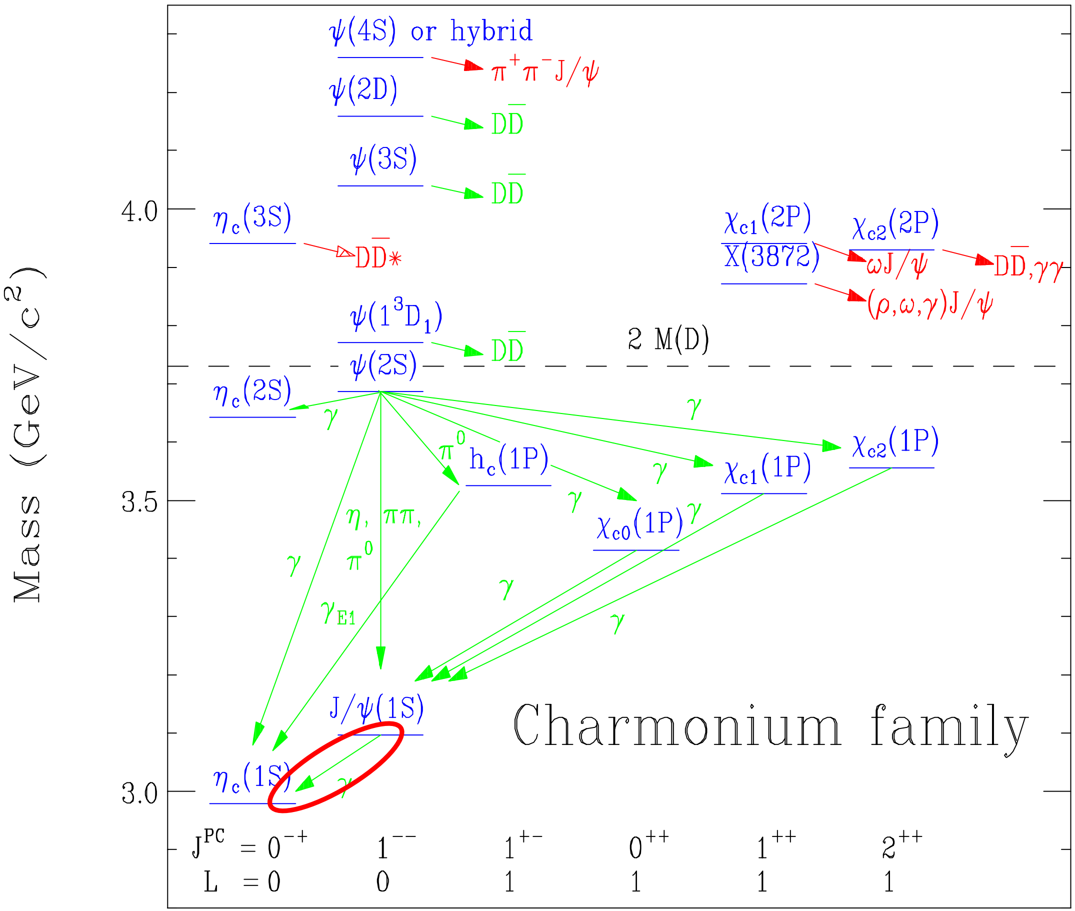
$J/\psi \rightarrow \gamma\eta_c$ decay

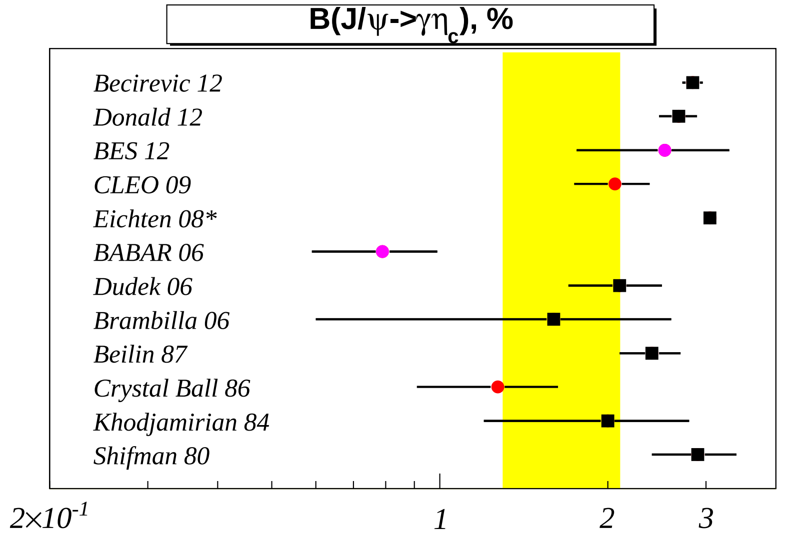


- M1 radiative transition
- photon energy
  ω_0 = 113.7 MeV
- angular distribution
  $d\Gamma/d\Omega \sim 1 + \cos^2\theta$
- η_C- meson width
  $\Gamma(\eta_C)$ = 29.7 ± 1.0 MeV
- η_C- meson mass
  $M(\eta_C)$ = 2981.0 ± 1.1 MeV
- branching fraction
  $B(J/\psi \rightarrow \eta_c\gamma) = (1.7 \pm 0.4)\%$

Branching fraction $B(J/\psi \to \gamma\eta_c)$

- Transition between 1S states of charmonium → rate can be easily calculated in potential models. Spatial part of wave function does not change and matrix element in leading approximation equals to one.

- Theoretical predictions:
  - **3.05% Potential model without relativistic corrections:** *E.E. Eichten et al., Rev. Mod. Phys., 2008, 80: 1161-1193*
  - **(2.4±0.3)% QCD sum rules :** *V.A. Beilin, A.V. Radyushkin, Sov. J. Nucl. Phys., 1987, 45: 342*
  - **(2. 84±0.12)% Lattice QCD:** *D. Besirevic, F.Sunfilippo, ArXiv:1206.1445*



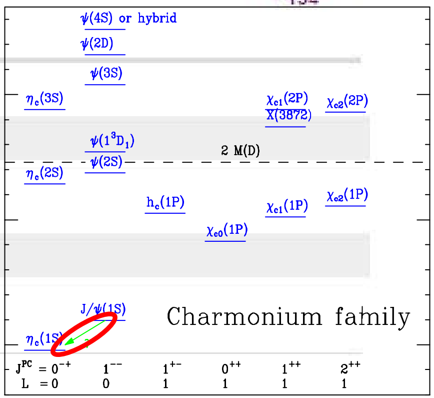
● experimental measurements ● indirect experimental measurements ■ theoretical predictions (* without relativistic corrections) ■ PDG average

- Experimental results (PDGLive 2013):

$\Gamma(\gamma\eta_c(1S))/\Gamma_{total}$ References History since 1990

Γ_{134}/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	COMMENT
1.7 ± 0.4	OUR AVERAGE	Error includes scale factor of 1.6.		
2.06 ± 0.32 ± 0.03		[1] MITCHELL 09	CLEO	$e^+e^- \to \gamma X$
1.27 ± 0.36		GAISER 86	CBAL	$J/\psi \to \gamma X$
* * * We do not use the following data for averages, fits, limits, etc. * * *				
0.79 ± 0.20	273 ± 43	[2] AUBERT 06E	BABR	$B^\pm \to K^\pm X_{c\bar{c}}$
seen	16	BALTRUSAITI... 84	MRK3	$J/\psi \to 2\varphi\gamma$
2.53±0.77		ABLIKIM 12	BES	$J/\psi \to 3\gamma$



Photon spectrum in $J/\psi \to \gamma \eta_c$ decay

- **Photon spectrum can be written in the form :**

$$\frac{dN_\gamma}{d\omega} = N_\Psi B \int d\omega' g(\omega, \omega') \frac{d\Gamma(\omega')}{d\omega'} \frac{\varepsilon(\omega')}{\Gamma_{\gamma\eta_C}},$$

where
B – decay branching fraction,
g(ω,ω′) – calorimeter response function,
ε(ω) – photon detection efficiency,
$\Gamma_{\gamma\eta_C}$ **– decay width,**

$$\frac{d\Gamma_{\gamma\eta_C}}{d\omega} = \frac{4}{3}\alpha \frac{e_c^2}{m_c^2} \omega^3 |M|^2 BW(\omega) \propto \omega^3 f(\omega) BW(\omega),$$

$$BW(\omega) \propto s/((s - M_{\eta_C}^2)^2 - s\Gamma_{\eta_C}^2), \quad s = M_\psi^2 - 2\omega M_\psi$$

$M=\langle\eta_c|j_0(\omega r/2)|J/\psi\rangle \to 1$ when $\omega \to 0$, $f(\omega)=1$ at $\omega \sim \omega_0$.

- **CLEO used $|M|^2=\exp(-\omega^2/8\beta^2)$ with β=65 MeV, but this is valid only for harmonic oscillator wave functions. For all other potentials dependence will be $\sim\omega^{-n}$ when $\omega \to \infty$.**

Crystal Ball J/ψ → γη$_C$ measurement

- 2.2M J/ψ decays
- Inclusive photon spectrum
- E_γ^3 factor in the convolution of the detector's response function with the η$_C$ Breit-Wigner resonance shape

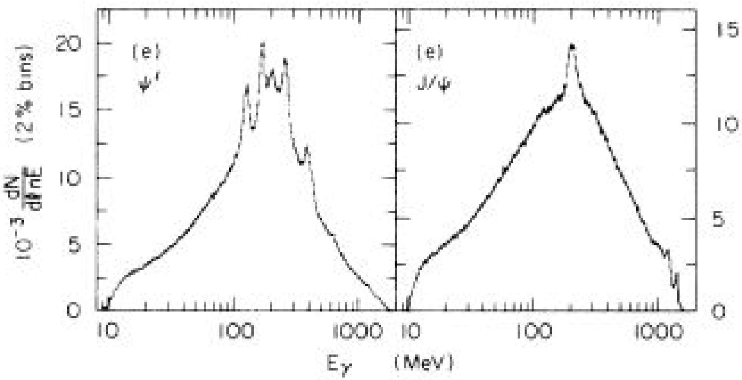


FIG. 7. Inclusive photon spectra from ψ' and J/ψ decays in 2% energy bins, obtained with the modified cut (e) on the lateral energy distribution as described in the text. This cut has less rejection power against charged particles than cut (d) as can be seen by the structure at ≃210 MeV, due to minimum ionizing particles.

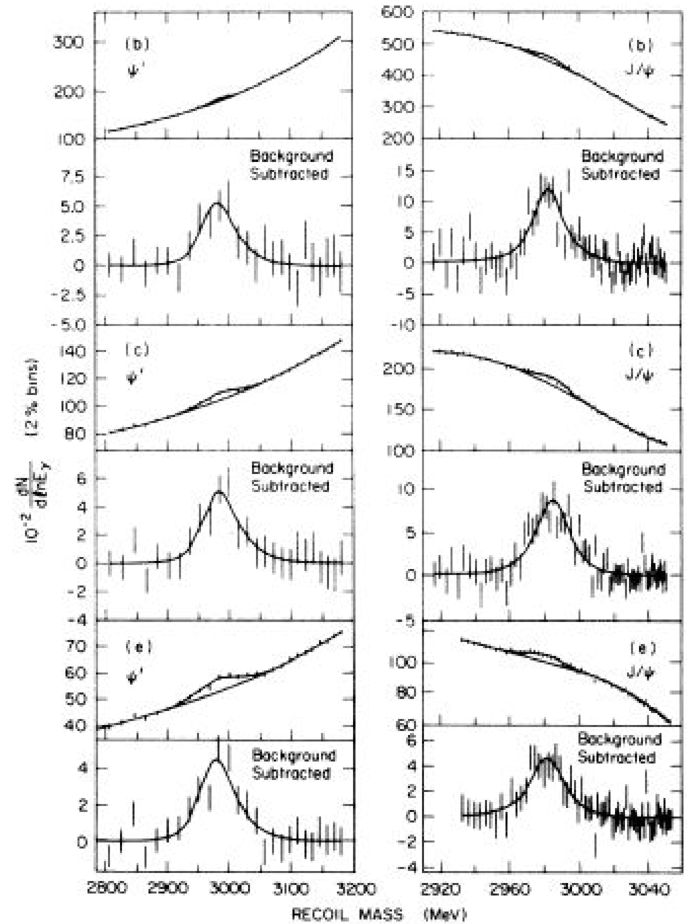
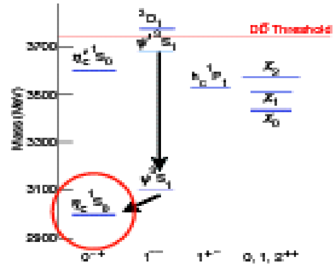


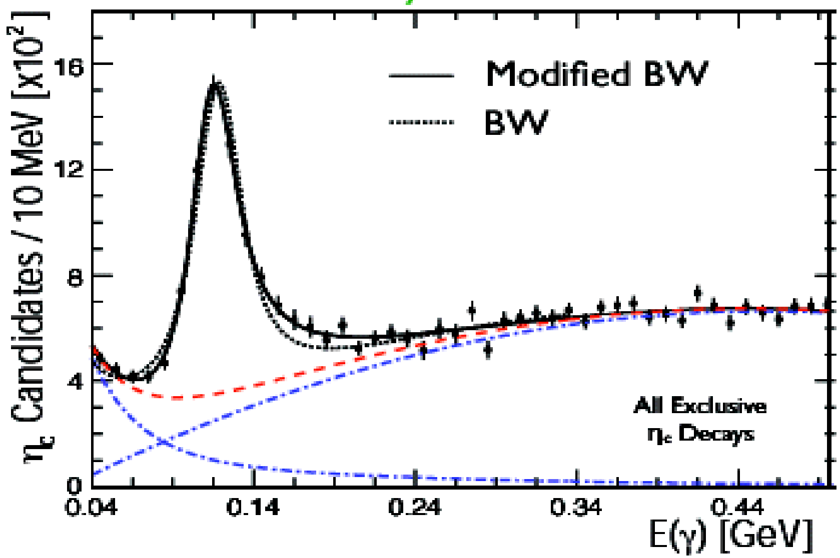
FIG. 8. Simultaneous fits to the η_c mass in the ψ' and J/ψ inclusive photon spectra. The data are plotted in 2% bins in the photon energy. The preferred resolution value of σ_0=2.7% is used in the fit. The spectra labeled (b) and (c) correspond to the photon selection criteria of the χ analysis. The spectra labeled (e) employ a modified cut on the lateral photon energy pattern as described in the text.

$J/\psi \rightarrow \gamma\eta_c$



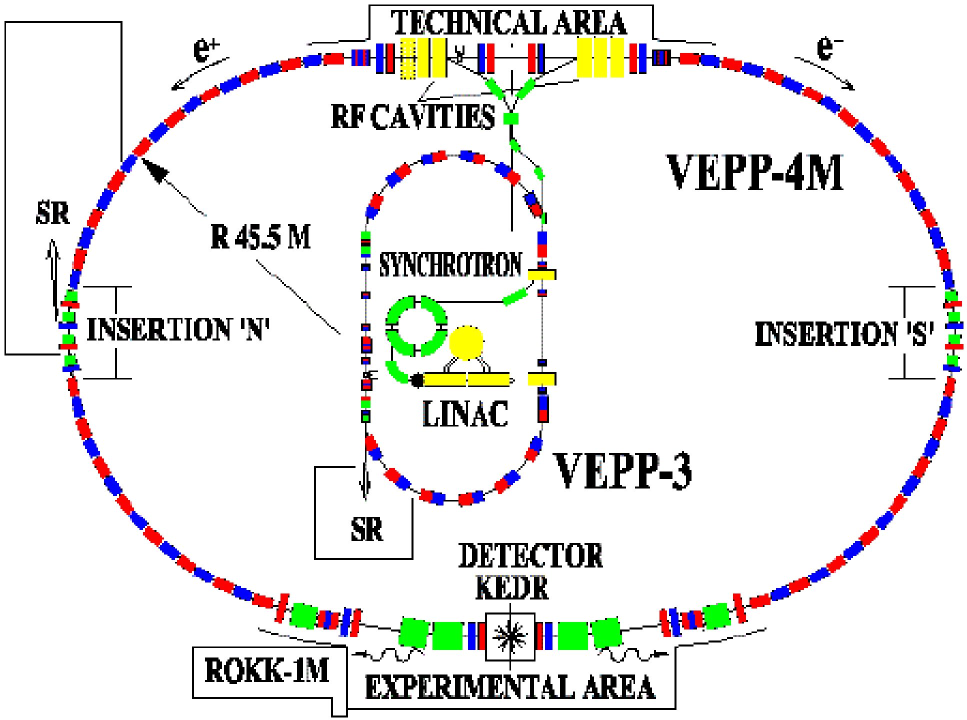
- $J/\psi \rightarrow \gamma\eta_c$ photon line shape spectrum also shows distortion
- Constrain background shapes using MC
  - falling hadronic shower background (floating scale factor)
  - free rising polynomial background
- Breit-Wigner alone provides poor fit to data
- Nominal fit is a Breit-Wigner modified by E_γ^3 and damped by $\exp(E_\gamma^2/\beta)$

CLEO Preliminary



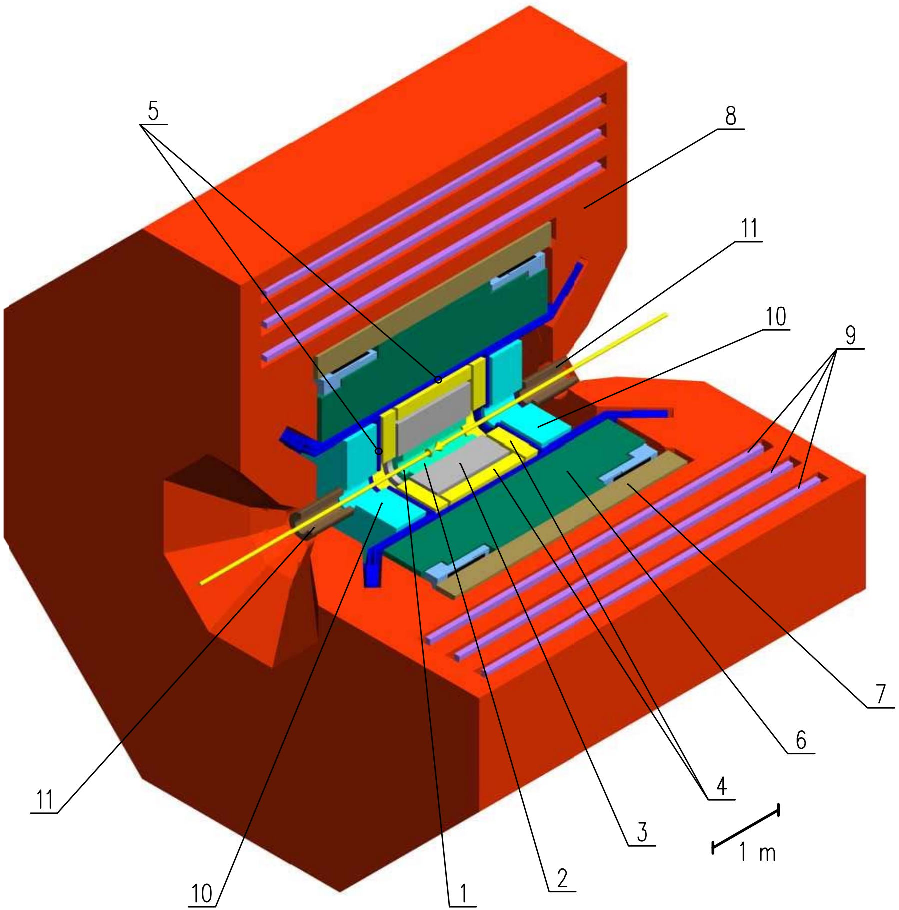
~5.5 MeV shift in ηc mass between BW and Modified BW fits

VEPP-4M collider



- Wide energy range E_{beam}=1÷6 GeV
- Peak luminosity 1.5×10^{30} $cm^{-2}s^{-1}$ at J/ψ
- Precise beam energy determination :
    - Resonant Depolarization Method, $\sigma_E \approx 1.5$ keV
        - Interpolation for DAQ runs $\sigma_E \approx 8÷30$ keV
    - IR-light Compton BackScattering, $\sigma_E < 100$ 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 (0.65 T)
8. Magnet yoke
9. Muon tubes
10. CsI-calorimeter
11. Compensation solenoid

- Luminosity is measured by single Bremsstrahlung in e^+ and e^- directions and by Bhabha scattering
- Scattering electron tagging system for two-photon studies

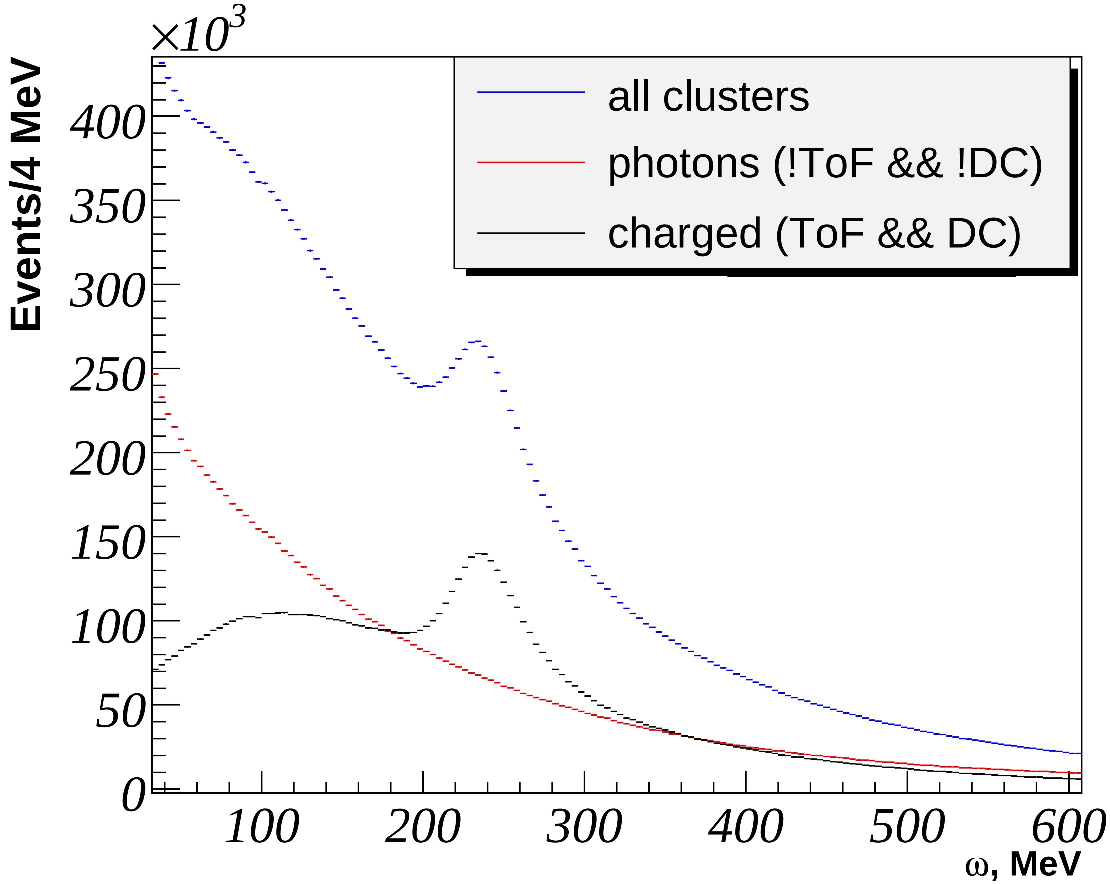
KEDR data

- Data were taken during 2007-2009 years :
  - Integrated luminosity at J/ψ peak **$L = 1.52 \pm 0.08$ pb^{-1}** is collected.
  - 3 J/ψ scans were performed; measured beam energy spread was used for calculation of the number of J/ψ produced : **$N_\psi = 6.3 \pm 0.3$ M**
  - LKr calorimeter response function : asymmetric Gaussian with σ_E=6.7 MeV at 110 MeV and a=-0.26

- At the first step multihadron decays of J/ψ were selected. These cuts effectively suppress background from cosmic rays, beam-gas interactions and QED events :
  - Total energy in clusters — $E_\Sigma > 0.8$ GeV
  - Number of clusters with $E_{cl} > 30$ MeV — $N_{cl} > 3$
  - Number of central DC tracks — $N_{trackIP} > 0$
  - No muon tubes activated in 3-rd layer — $N_{MU3} = 0$

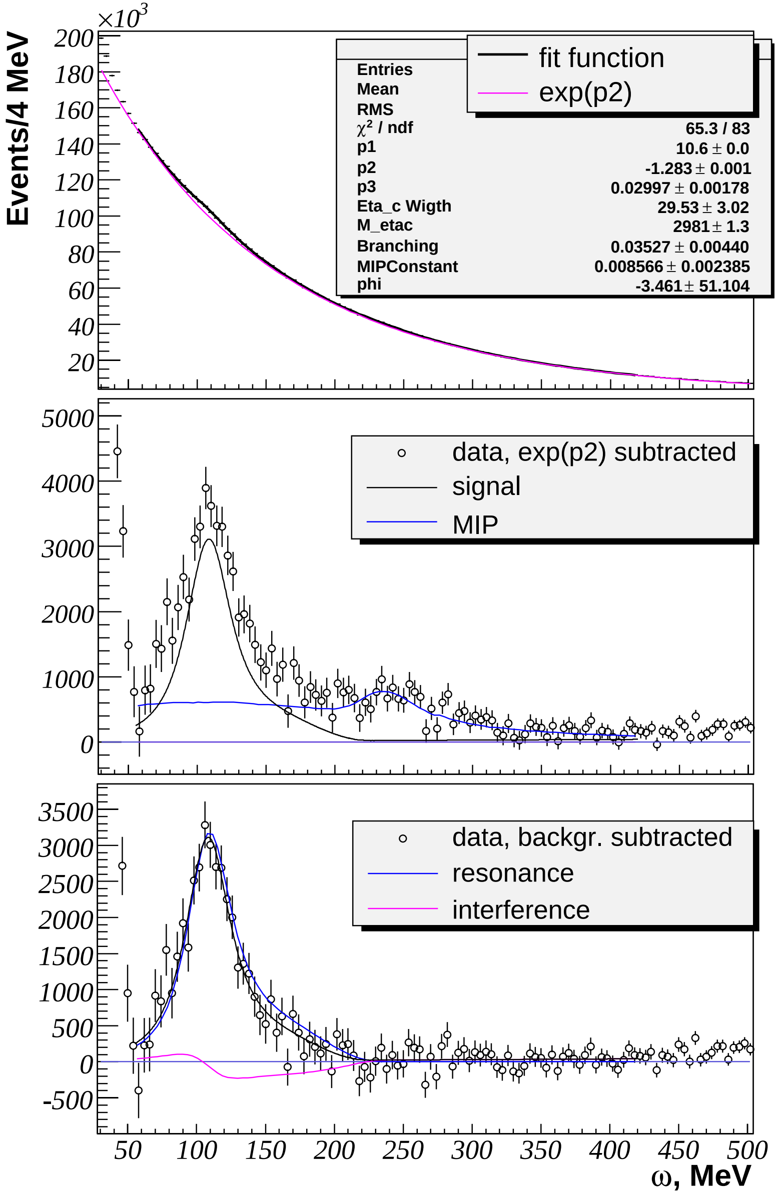
- At the second step photons in these events were identified. Photon is a cluster in liquid krypton calorimeter without tracks in DC attached to it and without TOF scintillator counters activated before cluster :
  - Angle between cluster and beam direction — $\Theta > 45°$
  - No tracks in drift chamber (DC) attached to cluster
  - No time of flight (ToF) scintillator counters activated before cluster

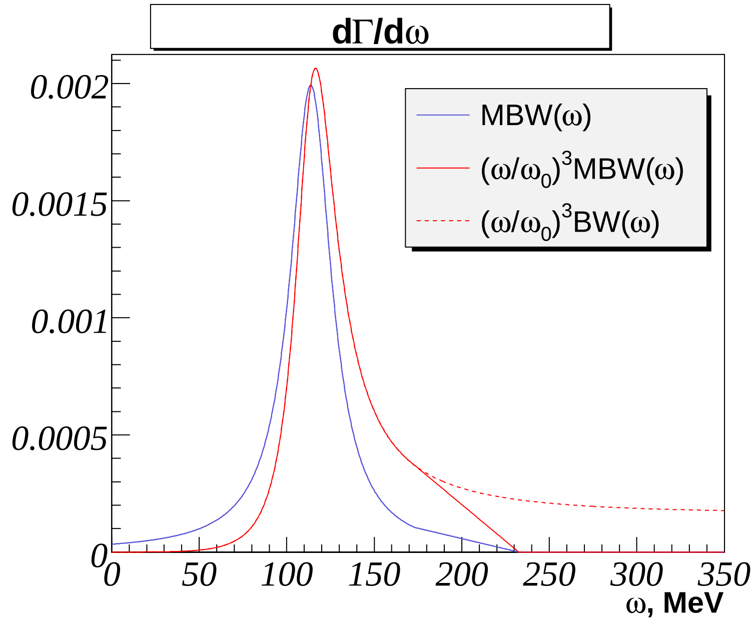
Inclusive spectra



Inclusive spectra: blue - spectrum of all clusters; red - photon spectrum; black - spectrum of charged particles, when ToF scintillator counter is activated before cluster and DC track is attached to cluster. The last was used for elimination of charged particles which were detected as neutral from the photon spectrum.

Подгонка с учетом интерференции





Форма линии выбрана в предположении, что Брейт-Вигнер правильно описывает форму резонанса до $\omega_0+2\Gamma$, а при $\omega>\omega_0+4\Gamma$ резонансом можно пренебречь. Подложка подгонялась функцией exp(p2)+C×MIP(ω).

	$M(\eta_C)$, МэВ	$\Gamma(\eta_c)$, МэВ	B, %
Данные	2981.4±1.3	29.5 ±3.0	3.57±0.44
PDG	2981.0±1.1	29.7±1.0	1.7±0.4

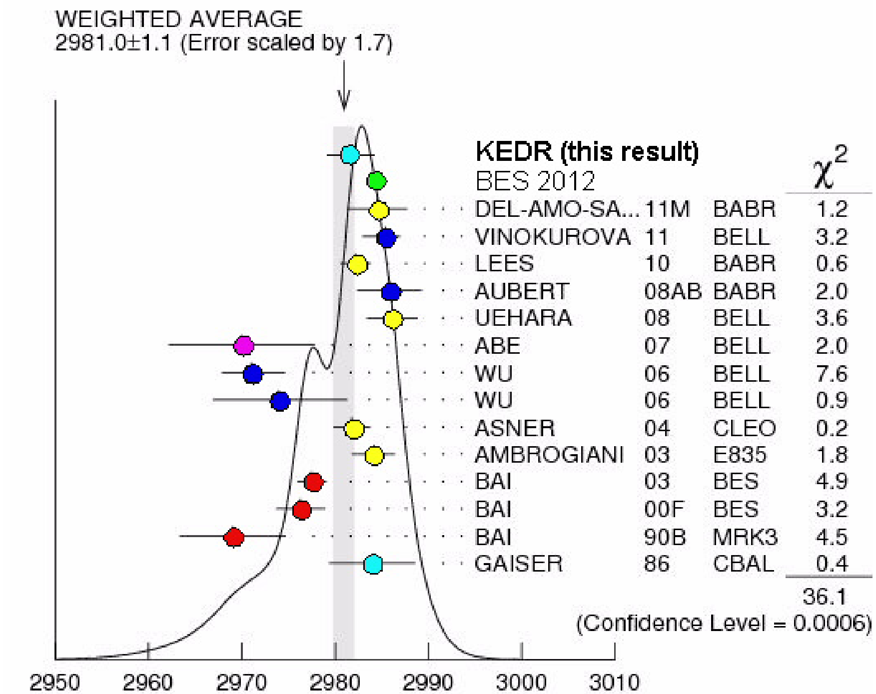
Systematic errors

Systematic error	$M(\eta_C)$, MeV	$\Gamma(\eta_C)$, MeV	$B(J/\psi\to\gamma\eta_C)$, %	$\Gamma^0_{\gamma\eta_C}$, keV
Background subtraction	0.4	1.5	0.11	0.08
Calorimeter response function	2.2	0.9	0.09	0.08
Line shape	0.3	4.3	-	0.13
η_C width	-	-	0.09	0.08
Interference	1.1	1.6	0.0	0.01
Photon selection efficiency	-	-	0.10	0.08
Total	**2.5**	**4.9**	**0.20**	**0.21**

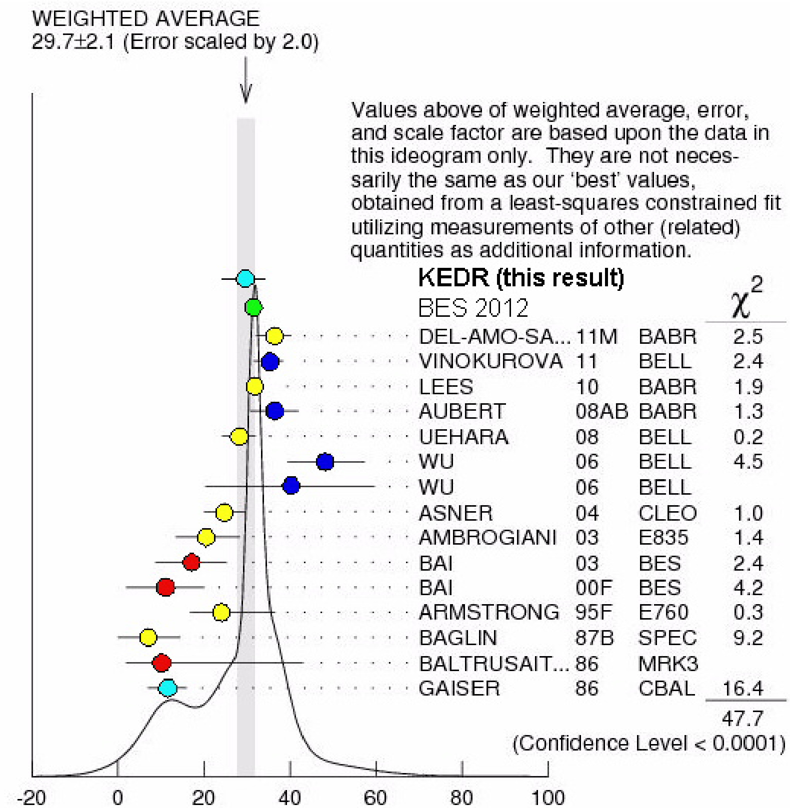
- *Background subtraction :* was estimated taking polynomial of 3-rd order, varying ranges of the fit, using or not ToF veto in photon selection
- *Calorimeter response function :* varying response function parameters in the fit and taking the difference between calibrations using $\pi^0\to2\gamma$ decays and $\psi'\to\gamma\chi_{C1}$, χ_{C2}; $\chi_{CJ}\to\gamma J/\psi$ transitions
- *Line shape :* estimated varying BW cut off parameters in the fit
- *η_C width :* varying 29.7±1.0 MeV (PDG value)
- *Interference :* varying $N_1/S(\omega_0)$ by 50% and including N_2 term in the fit
- *Photon selection efficiency :* from the difference of ε_{mh} and ε'_{mh} in MC simulation and ε_γ determination

Results on η_c mass and width

η_C mass (MeV)



η_C width (MeV)



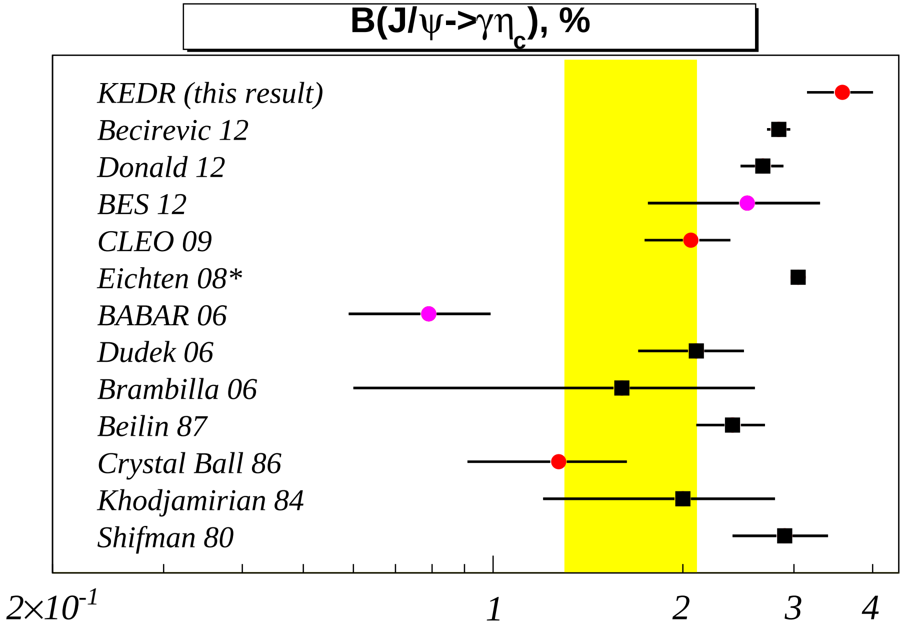
● J/ψ decays ● J/ψ decays (ω^3 factor) ● B decays ● $\gamma\gamma$ or $pp \to \eta_C$ ● $ee \to J/\psi + cc$ ● $\psi(2S)$ decays

KEDR results	**PDG**
$M(\eta_c)$ = **2981.4 ± 1.0 ± 2.5 MeV**	**2981.0 ± 1.1 MeV**
$\Gamma(\eta_c)$ = **29.5 ± 3.0 ± 4.9 MeV**	**29.7 ± 1.0 MeV**

Result on $B(J/\psi \to \gamma \eta_c)$ and conclusions

- Photon line shape in the radiative $J/\psi \to \eta_c \gamma$ decay is asymmetric. The branching value of this decay and η_c mass are sensitive to the line shape, and it should be taken into account during measurement.

- Our result on $B(J/\psi \to \eta_c \gamma)$ is higher than the old Crystal Ball and CLEO results and is consistent with the new Lattice QCD theoretical predictions.



● experimental measurements ● indirect experimental measurements ■ theoretical predictions (* without relativistic corrections) ■ PDG average

KEDR result

$$B(J/\psi \to \gamma \eta_c) = (3.58 \pm 0.38 \pm 0.20)\%$$

PDG

$$(1.7 \pm 0.4)\%$$