Search for Heavy Quark Resonances in Two-Photon collisions in the L3 detector

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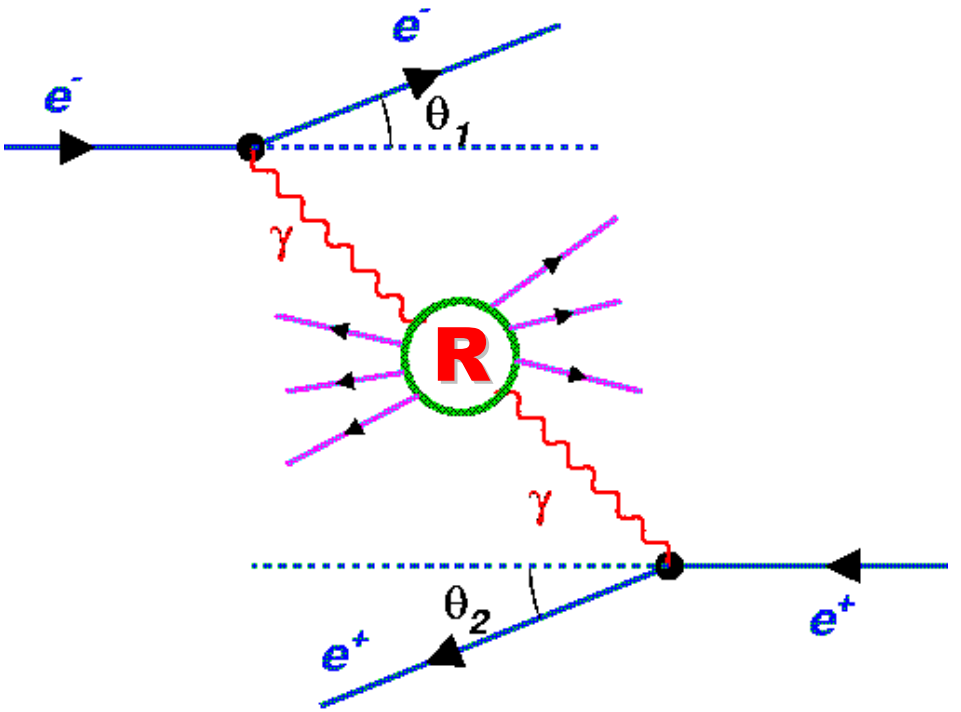
- ⇨ Search for η_c meson (status)
- ⇨ Search for η_b meson (status)
- ⇨ Outlook

- Resonance formation



- Outgoing e^-e^+ are undetected ("No TAG") → Quasi-real photons
- Final state → neutral unflavored meson R ,with C=+1

η_c(z-pole)

- Was studied in z-pole data

$$\sqrt{s} = 91 GeV$$

- L=140pb^{-1}
- Channels:

$\pi^+\pi^-\pi^+\pi^-$

$\pi^+\pi^-K^+K^-$

$K_s^0 K^\pm\pi^\pm$

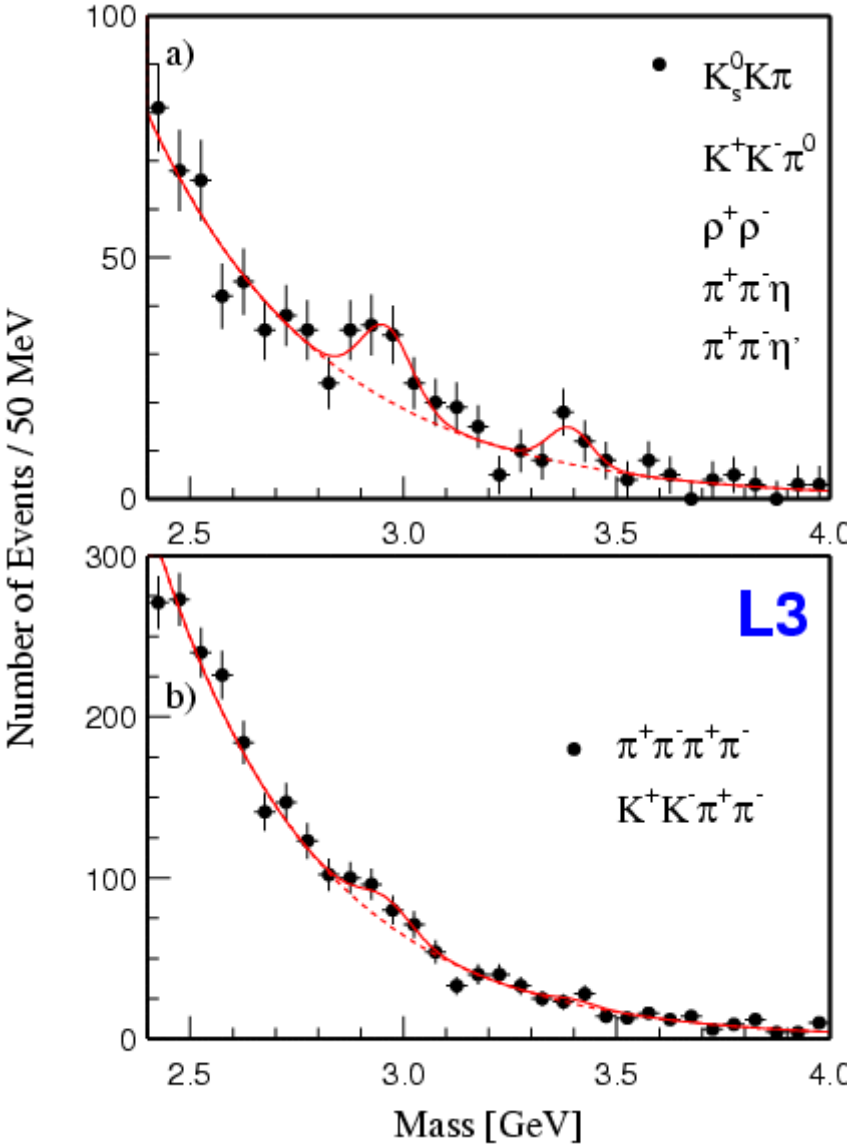
$K^+K^-\pi^0$

$\pi^+\pi^-\eta$

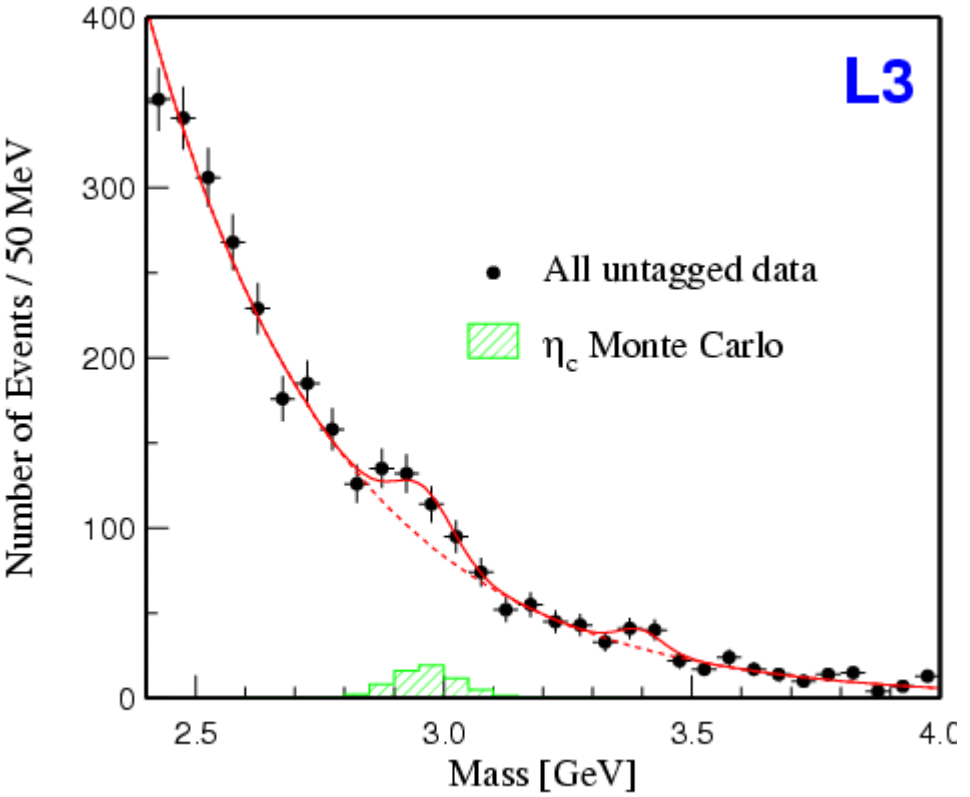
$\pi^+\pi^-\eta'$

$\rho^+\rho^-$

Physics Letters B 461 (1999) 155-166



η_c(z-pole)



Resonance	$\Gamma\gamma\gamma$[keV](BR)	Mass [GeV]
η_c	6.9±1.7±0.8	2.974±0.018
η'_c	<2.0	3.594
χ_{c0}	<5.5	3.417±0.003
χ_{c2}	<1.4	3.556

η_b Theoretical Prediction

Possible hypothesises

hypothesis	m(η_b)	
naive estimates		
hyperfine splitting	9.45 GeV	F.E. Close[1]
hyperfine(α_s, r_{eff})	9.42 GeV	H.Anlauf, T.Mannel
spin averaged masses	9.40 GeV	see G.Bali (review)
QCD calculations		
lattice NRQCD	9.38 GeV	A.El-Khadra[2], L.Marcantonio[3], G.Bali[4]
lattice potential	9.37 GeV	G.Bali[5]
1/m-expansion	9.40 GeV	S.Narison[6]
potential model	9.36 GeV	T.Barnes[7], E.J.Eichten[8], D.Ebert[9]
pQCD	9.41 GeV	N. Brambilla[10]

⇨ m(η_b)$\simeq$ 9.32 to 9.43 GeV

⇨ $\Gamma_{\gamma\gamma}(\eta_b) = 557 \pm 85$eV

Previous searches

- In radiative decay of the $\Upsilon(3S) \rightarrow \gamma\, \eta_b$ (CUSB & CLEO)
  - CLEO(1994)

    $BR(\Upsilon(3S) \rightarrow \pi\pi\, h_b) \times BR(h_b \rightarrow \gamma\, \eta_b) < 0.1\%$ at 90% C.L.

    for η_b mass range from 9.32 GeV to 9.46 GeV

    Phys. Rev. D49(1994) 40

- In two-photon collisions
  - ALEPH(2002)

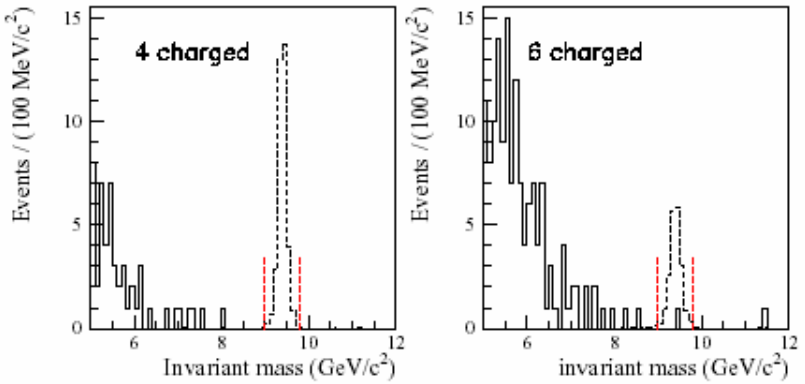
    * $\Gamma_{\gamma\gamma}(\eta_b) \times BR(4 \text{ charged part}) < 48$ eV at 95% C.L.

      0 events found (background: 0.30±0.25)

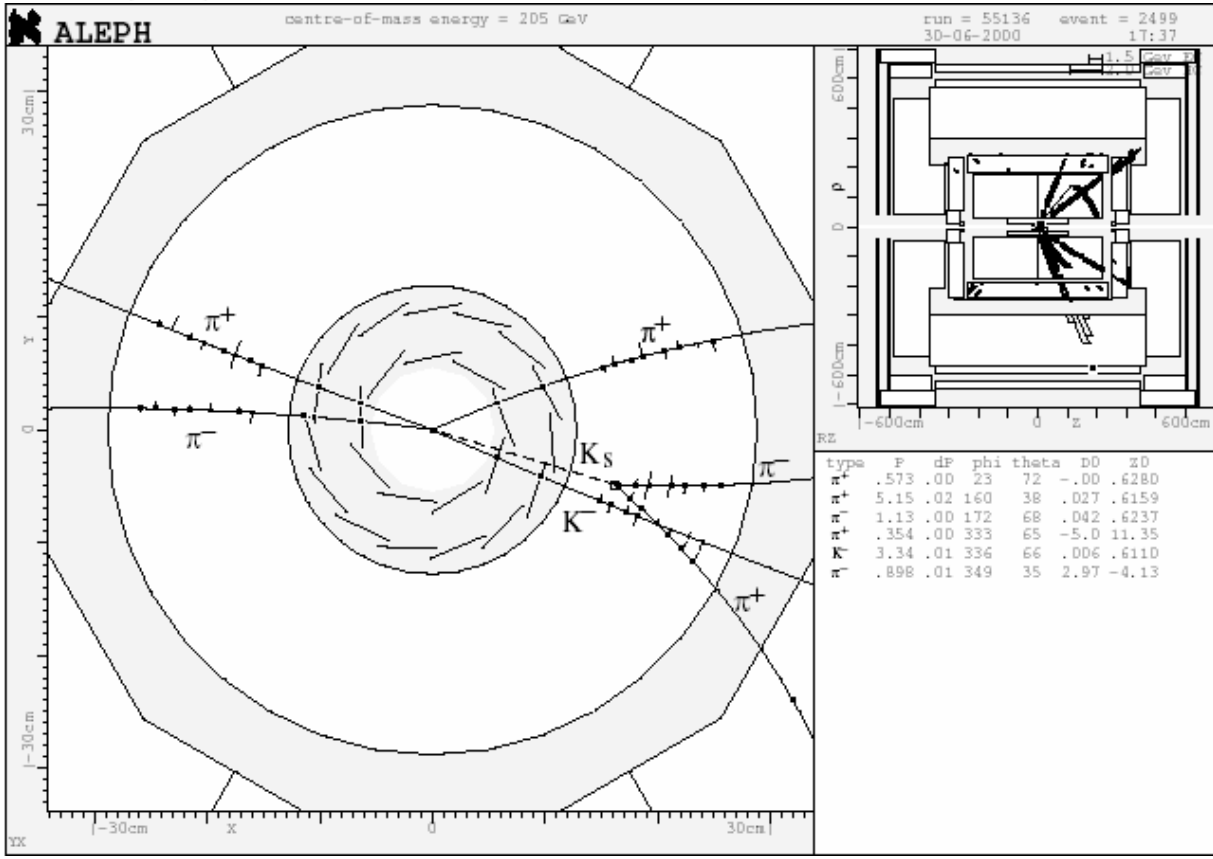
    * $\Gamma_{\gamma\gamma}(\eta_b) \times BR(6 \text{ charged part}) < 132$ eV at 95% C.L.

      1 candidate m=9.30±0.04 GeV (background: 0.70±0.34)

    Phys. Lett. B530 (2002)


4 charged
6 charged
Events / (100 MeV/c^2)
Invariant mass (GeV/c^2)
invariant mass (GeV/c^2)

ALEPH


ALEPH
centre-of-mass energy = 205 GeV
run = 55136 event = 2499
30-06-2000 17:37
π^+
π^-
K_S
K^-
type P dP phi theta D0 Z0
π^+ .573 .00 23 72 -.00 .6280
π^+ 5.15 .02 160 38 .027 .6159
π^- 1.13 .00 172 68 .042 .6237
π^+ .354 .00 333 65 -5.0 11.35
K^- 3.34 .01 336 66 .006 .6110
π^- .898 .01 349 35 2.97 -4.13

High energy data: $< \sqrt{s} >= 195 GeV$

⇨ $\int \mathcal{L} = 610 pb^{-1}$

⇨ 4 times bigger statistic

⇨ All decay modes are the same

⇨ PreSelecion is:

- ⇨ 2tracks, 4tracks, 6tracks
- ⇨ 2tracks 2photons, 4tracks 2photons, 6tracks 2photons

⇨ Clean signal from η_c

⇨ The most significant decay modes:

- ⇨ $\pi^+\pi^-\eta$, $\eta \to \gamma\gamma$
- ⇨ $K^+K^-\pi^+\pi^-$
- ⇨ $K_s^0 K^{\pm}\pi^{\pm}$
- ⇨ **$K^+K^-\pi^0$**

$\eta_{c/b}$ Selection

⇨$\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-K^+K^-$

Four tracks and no photons. Using dE/dx measurement π and K are distinguished with 8% to 21% misidentification

⇨$K_s^0 K^\pm\pi^\pm$

Geometrical reconstruction of the secondary vertex of $K_s^0 \rightarrow \pi^+\pi^-$, invariant mass $M(\pi^+\pi^-)=M(K_s^0) \pm 30$MeV

⇨$K^+K^-\pi^0$

Two photons reconstructed as π^0 and two tracks observed.

$\eta_{c/b} \rightarrow \pi^+\pi^-\pi^0$ is forbidden by **G** parity conservation.

⇨$\pi^+\pi^-\eta$

$\eta \rightarrow \gamma\gamma$ reconstruction, $\eta \rightarrow \pi^+\pi^-\pi^0$ with $|M(\pi^+\pi^-\pi^0)-M(\eta)|< 40$MeV

⇨$\pi^+\pi^-\eta'$, $\eta' \rightarrow \pi^+\pi^-\eta$

reconstruction with $|M(\pi^+\pi^-\pi^0)-M(\eta')|< 50$MeV, $\eta' \rightarrow \rho^0\gamma$

⇨$\rho^+\rho^-$

$|M(\pi^\pm\pi^0)-M(\rho^\pm)|< 25$MeV

η_b Selection

I. Preselection: to define good tracks with p_T>150 MeV and e.m. cluster compatible with photons from π^o (E_γ> 80 MeV)

II. Selection: $\gamma\gamma \rightarrow R \rightarrow$ n charged particles

- n tracks (no other accidental tracks must be present)
- $\Sigma\, p_T^2 < 0.1\ GeV^2$
- Reject: photon conversions, cut: $m(e^+e^-)>50$ MeV
  $\gamma\gamma \rightarrow \tau^+\tau^-$, cut: $m(3\pi) > 1.9$ GeV

Explored channels:

- ⇨2 track events+ 2 photons
- ⇨4track events
  - ➢+ 1,2 photons
- ⇨6track events
  - ➢+ 2 photons

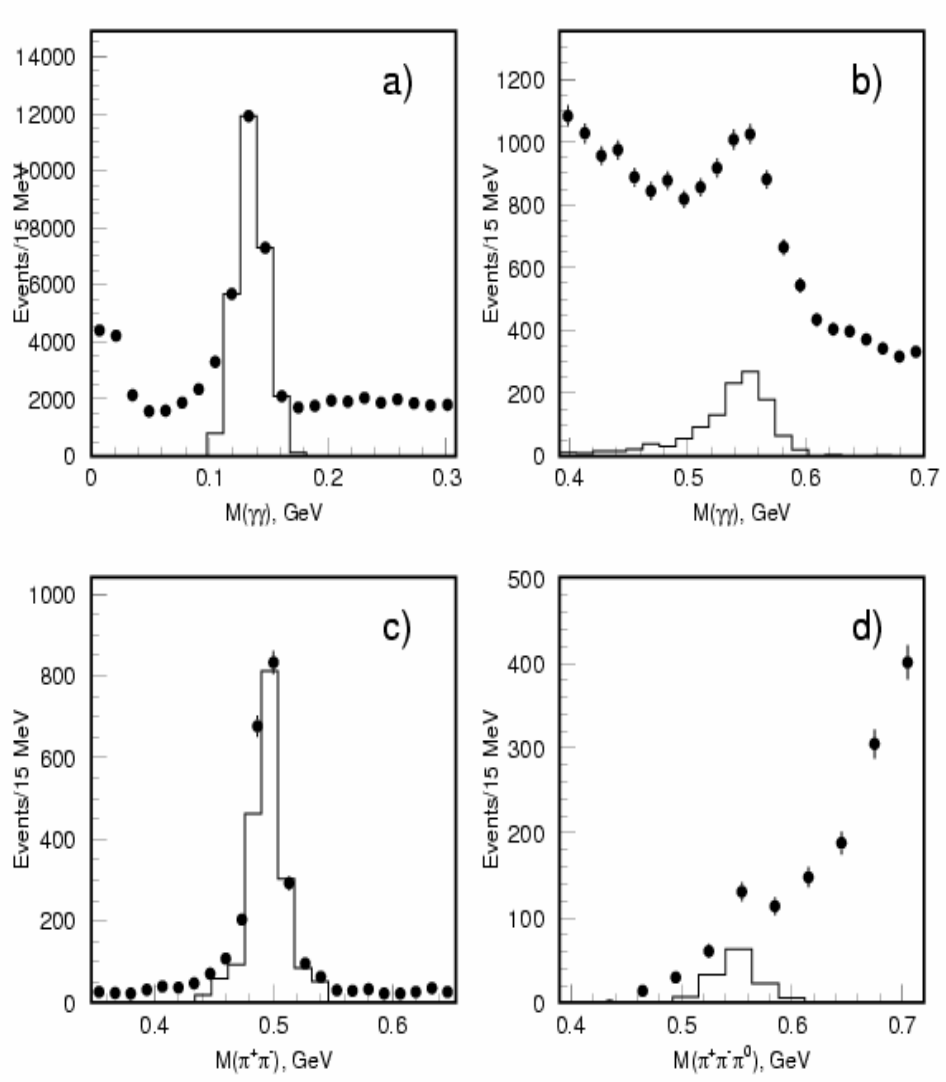
$\eta_{c/b}$ Selection

⇨a) Effective mass of two photons in $K^+K^-\pi^0$ sample

⇨b) Effective mass of two photons in $\pi^+\pi^-\eta$ sample

⇨c) Effective mass of $\pi^+\pi^-$ from $K_s^0 \rightarrow \pi^+\pi^-$ secondary vertex

⇨c) Effective mass of three pions photons in $\pi^+\pi^-\eta$ sample



$e^+e^- \to e^+e^- K^+K^- \pi^0$ η_c

⇨ π^0 reconstructed from 2γ

⇨ $P(K_+K_-)/(P(\pi^+\pi^-)+P(K^+K^-))>20\%$

Data(fit):

$M(\eta_c)=2.965+/-0.017$ GeV

$\sigma(\eta_c)=0.092+/-0.011$ GeV

MC(fit):

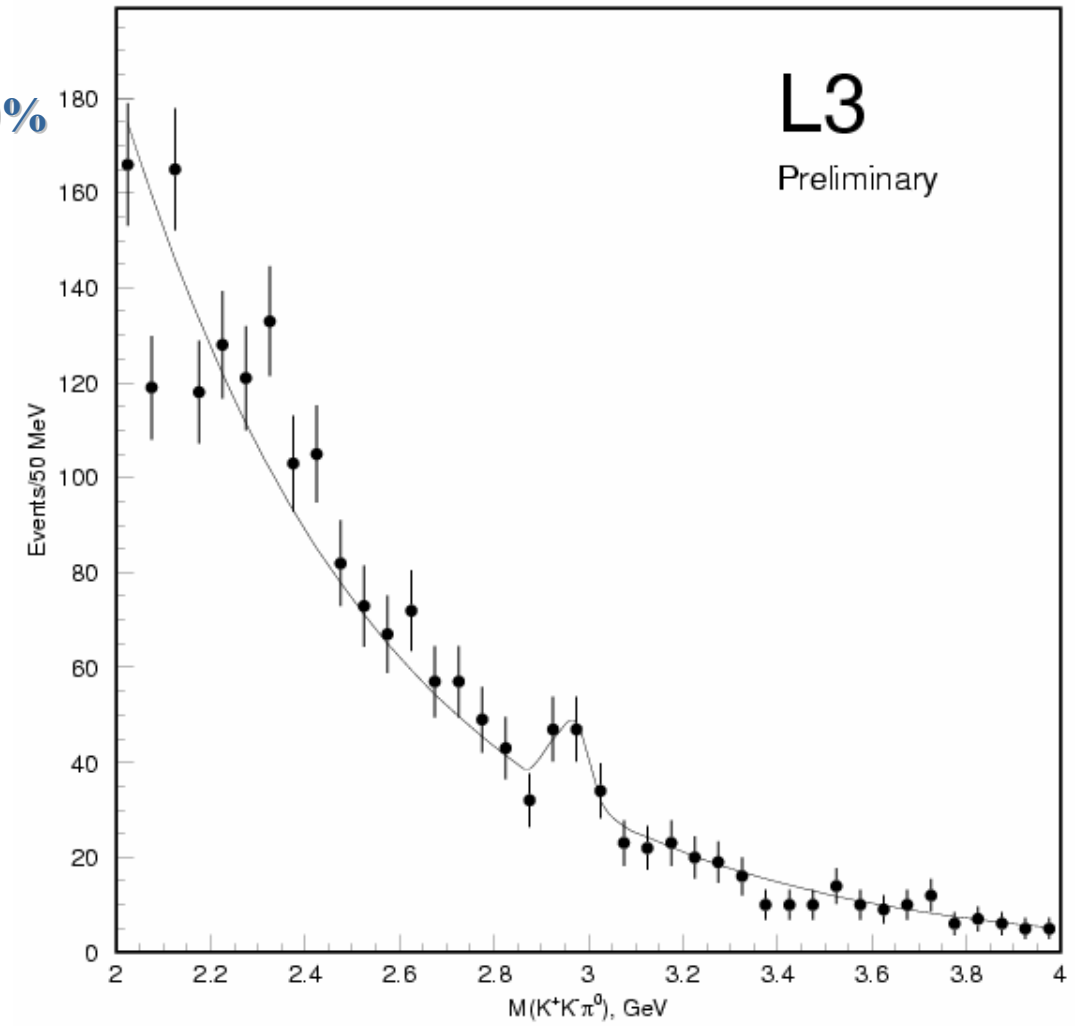
(generated with PDG parameters)

$M(\eta_c)=2.961+/-0.002$ GeV

$\sigma(\eta_c)=0.083+/-0.002$ GeV

$\varepsilon=3.68+/-0.08$

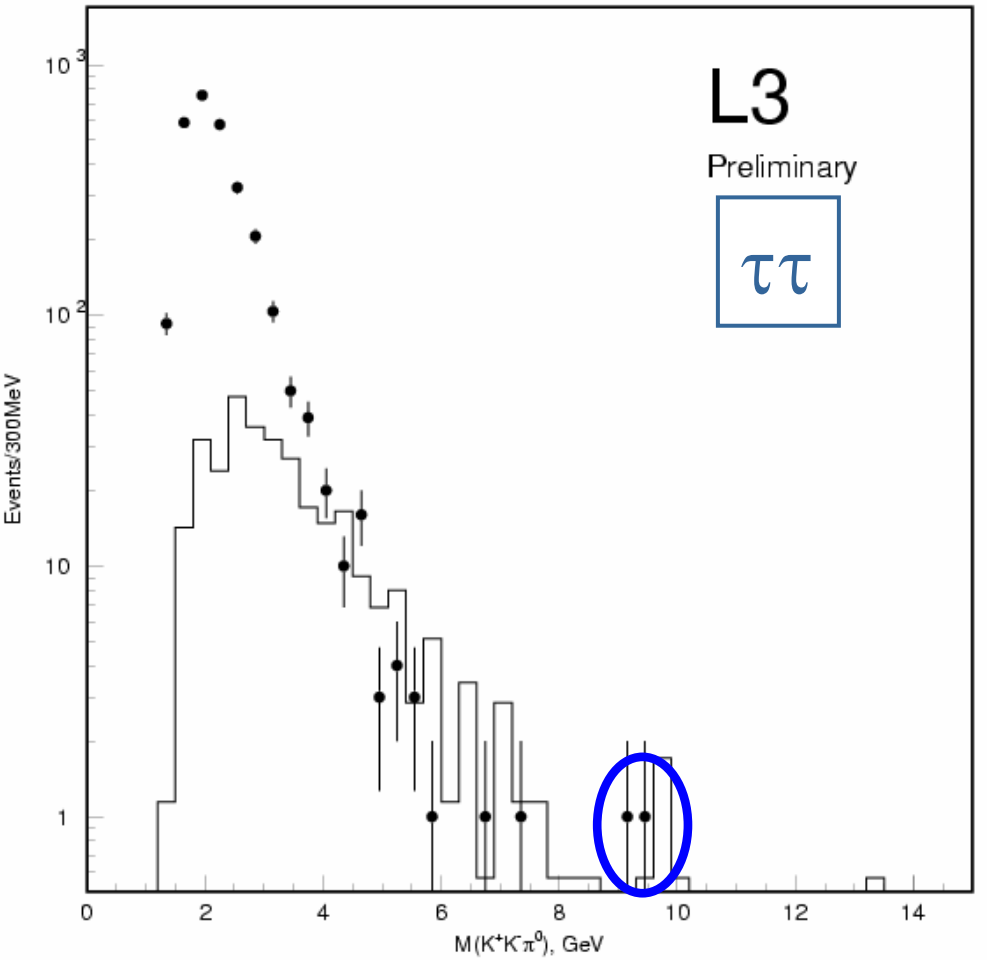
$N_{ev}=30+/-15$



$e^+e^- \to e^+e^- K^+K^- \pi^0$ η_b

- π^0 reconstructed from 2γ
- $P(K_+K_-)/(P(\pi^+\pi^-)+P(K^+K^-))>50\%$

- M=9.168 +/-0.300 GeV
- M=9.519 +/-0.300 GeV



$e^+e^- \to e^+e^-\pi^+\pi^-\eta \to \gamma\gamma$ η_c

- η reconstructed from 2γ
- Two tracks required

Data(fit):

$M(\eta_c) = 2.953 \pm 0.025$ GeV

$\sigma(\eta_c) = 0.067 \pm 0.017$ GeV

MC(fit):

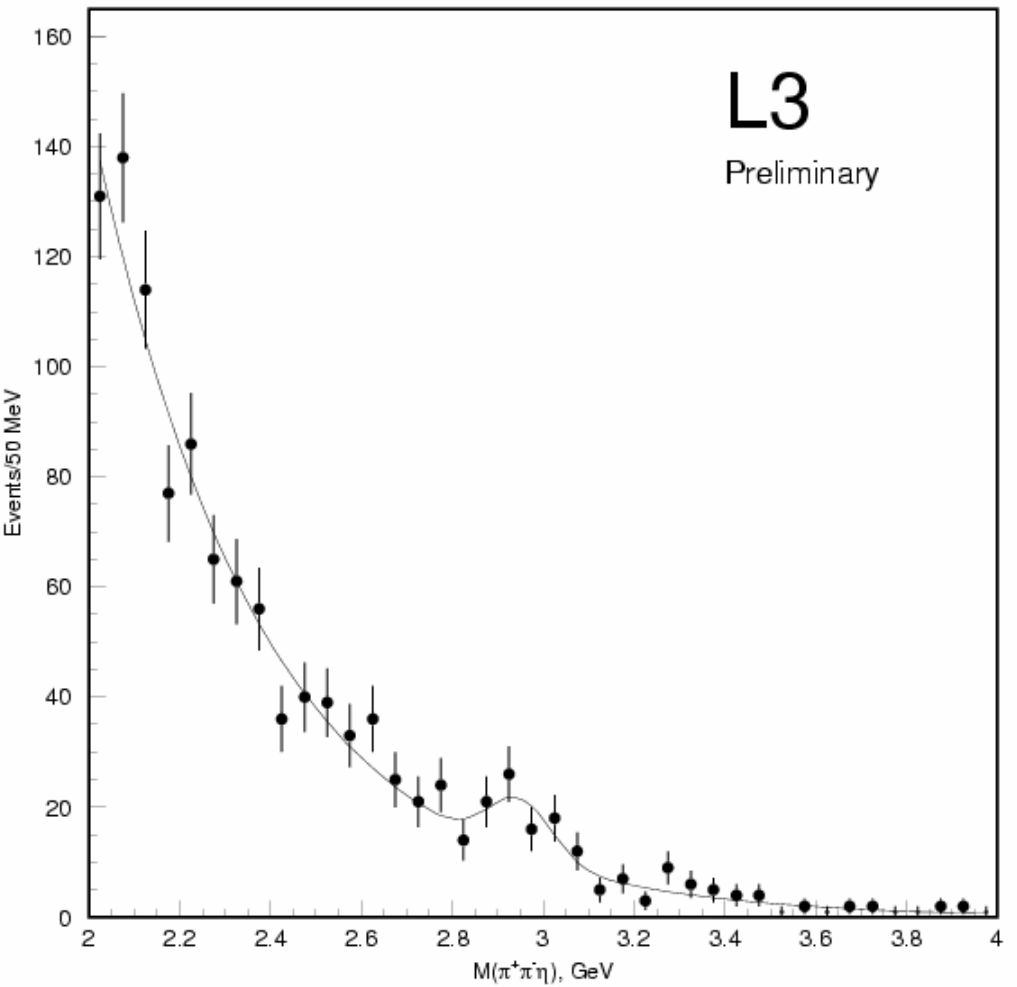
(generated with PDG parameters)

$M(\eta_c) = 2.965 \pm 0.003$ GeV

$\sigma(\eta_c) = 0.077 \pm 0.003$ GeV

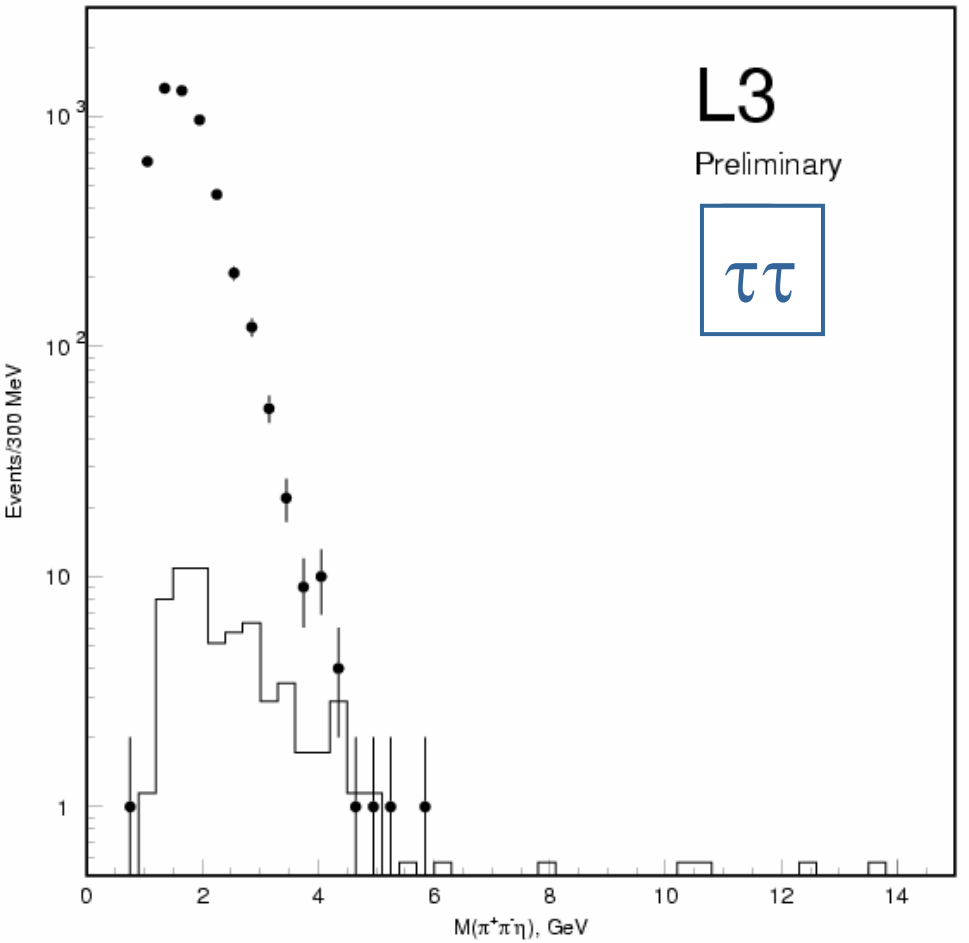
$\varepsilon = 5.42 \pm 0.15$

$N_{ev} = 35 \pm 10$



$e^+e^- \to e^+e^-\pi^+\pi^-\eta \to \gamma\gamma$ η_b

- η reconstructed from 2γ
- Two tracks required



$e^+e^- \to e^+e^-\pi^+\pi^-\eta' \to \rho^0\gamma$ η_c

⇨ η' reconstructed from $\rho^0\gamma$

⇨ Four tracks required

Data(fit):

$M(\eta_c)$=2.973+/-0.045 GeV

$\sigma(\eta_c)$=0.071+/-0.037 GeV

MC(fit):

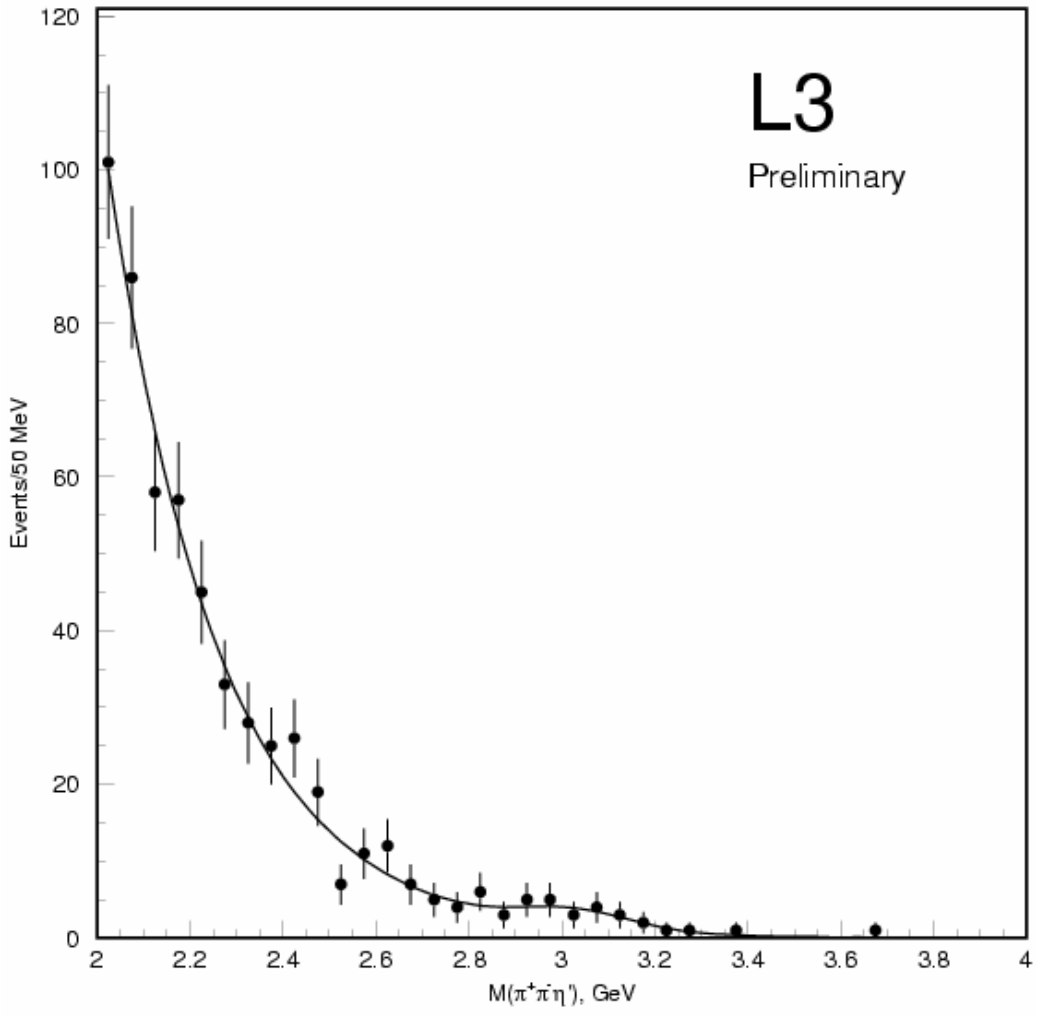
(generated with PDG parameters)

$M(\eta_c)$=2.981+/-0.005 GeV

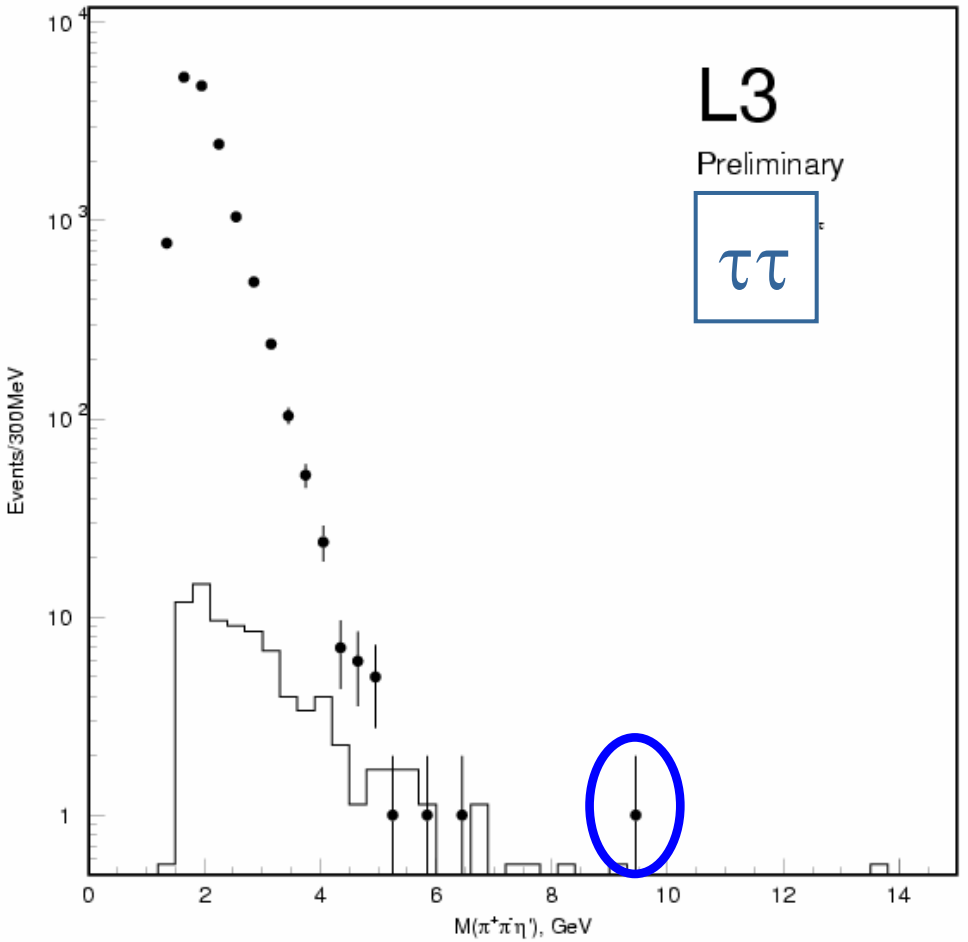
$\sigma(\eta_c)$=0.084 +/-0.005 GeV

ε=0.41

N_{ev}=5+/-4



$e^+e^- \rightarrow e^+e^-\pi^+\pi^-\eta' \rightarrow \rho^0\gamma$ η_c



⇨ρ^0 reconstructed from 2π

⇨$\eta' \rightarrow \rho^0\gamma$

⇨M=9.35 +/-0.320GeV

$e^+e^- \rightarrow e^+e^- K_s K\pi$ η_c

⇨Geometrical reconstruction of the secondary vertex of $K_s^0 \rightarrow \pi^+\pi^-$

⇨ $M(\pi^+\pi^-)=M(K_s^0)\pm 30$MeV

⇨π/K separation by dE/dx

Data(fit):

$M(\eta_c)=2.956+/-0.022$ GeV

$\sigma(\eta_c)=0.064+/-0.022$ GeV

MC(fit):

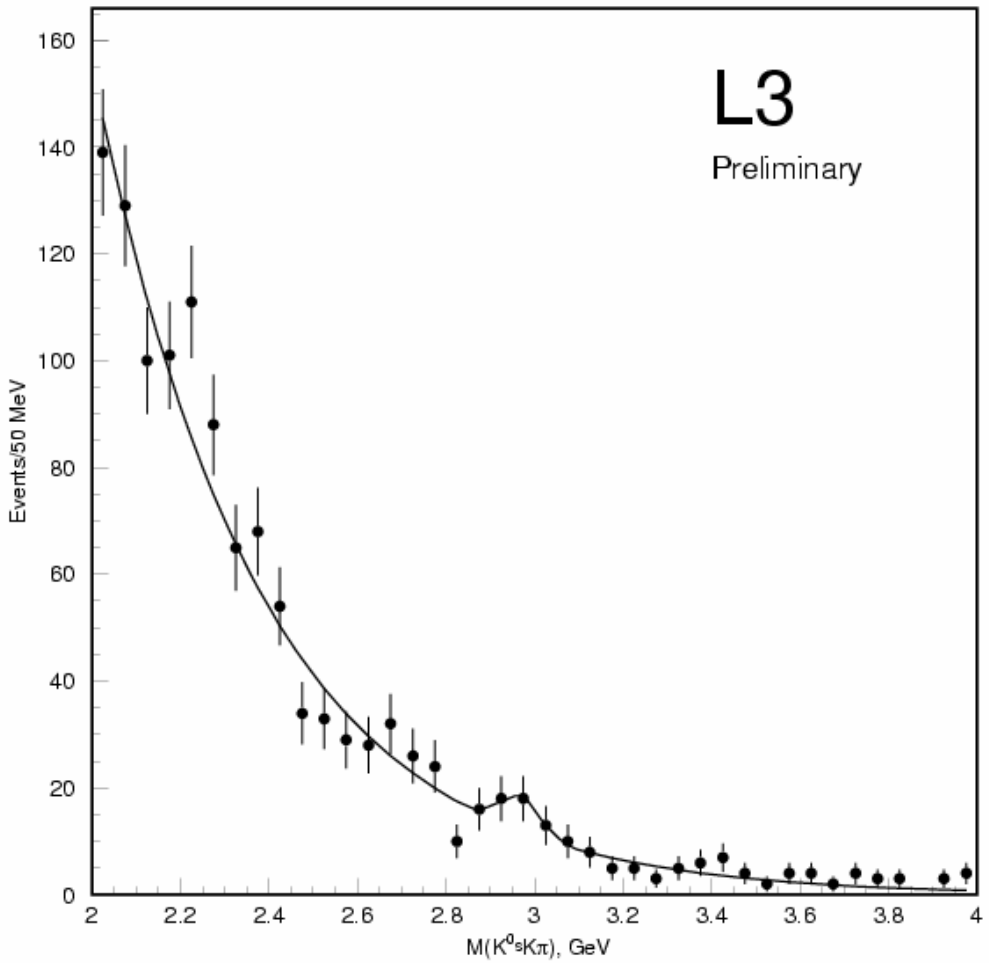
(generated with PDG parameters)

$M(\eta_c)=2.975+/-0.003$ GeV

$\sigma(\eta_c)=0.082+/-0.003$ GeV

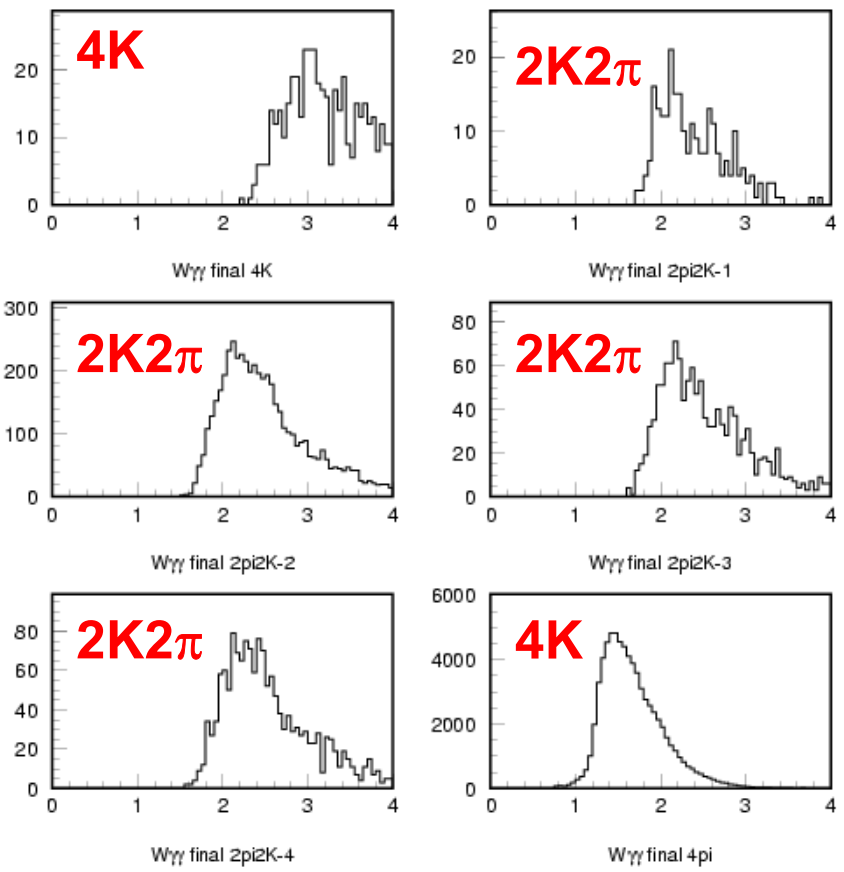
$\varepsilon=2.23+/-0.05$

$N_{ev}=35+/-12$



$e^+e^- \rightarrow e^+e^-$ 4tracks

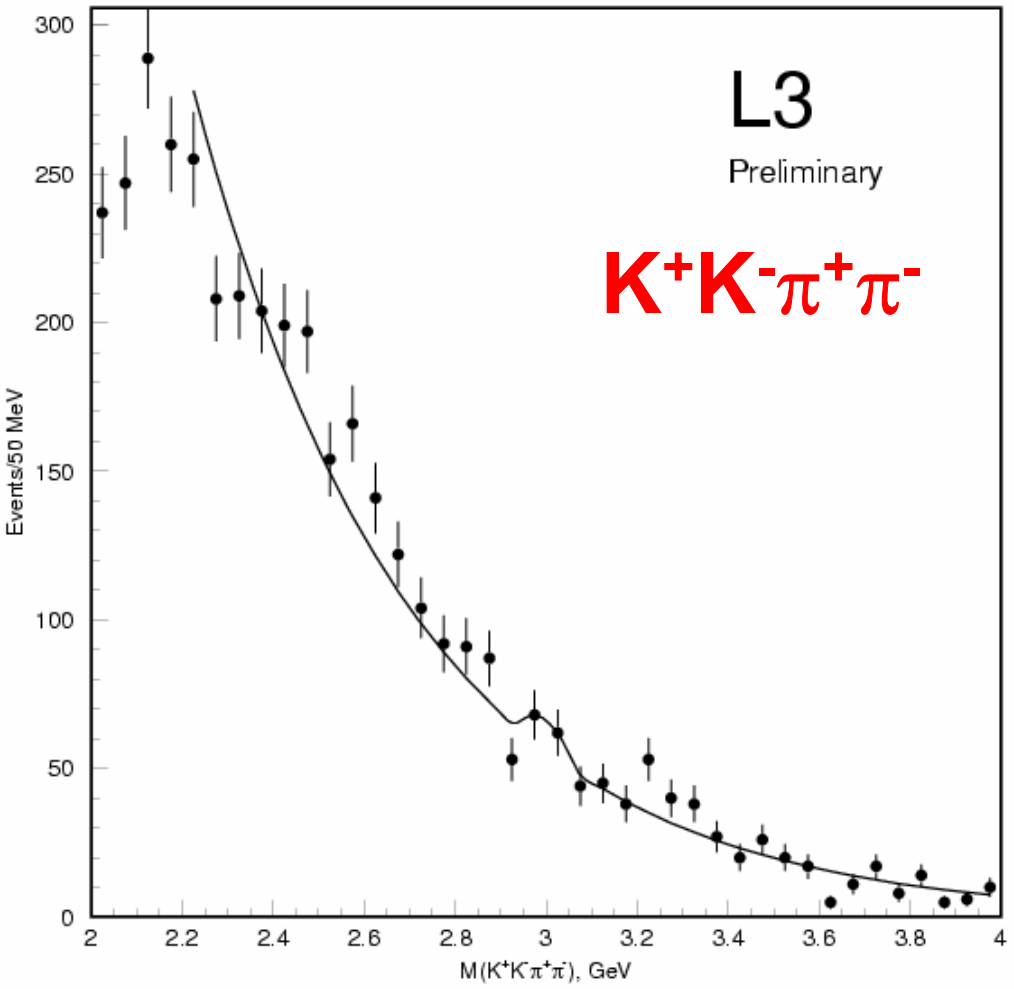
η_c



4K-near threshold

4π - dominated by background

So we are using only $2K2\pi$ data



Data(fit):

$M(\eta_c)$=2.989+/-0.011 GeV

$\sigma(\eta_c)$=0.092+/-0.019 GeV

MC(fit):

(generated with PDG parameters)

$M(\eta_c)$=2.957+/-0.002 GeV

$\sigma(\eta_c)$=0.066 +/-0.002 GeV

ε=2.52+/-0.05

N_{ev}=30+/-10

Low statistics channels

η_c

⇨a) $\gamma\gamma \rightarrow R \rightarrow \pi^+\pi^-\eta(\pi^+\pi^-\pi^0)$

Nev=4+/-3

⇨b) $\gamma\gamma \rightarrow R \rightarrow \pi^+\pi^-\eta'(\pi^+\pi^-\eta)$

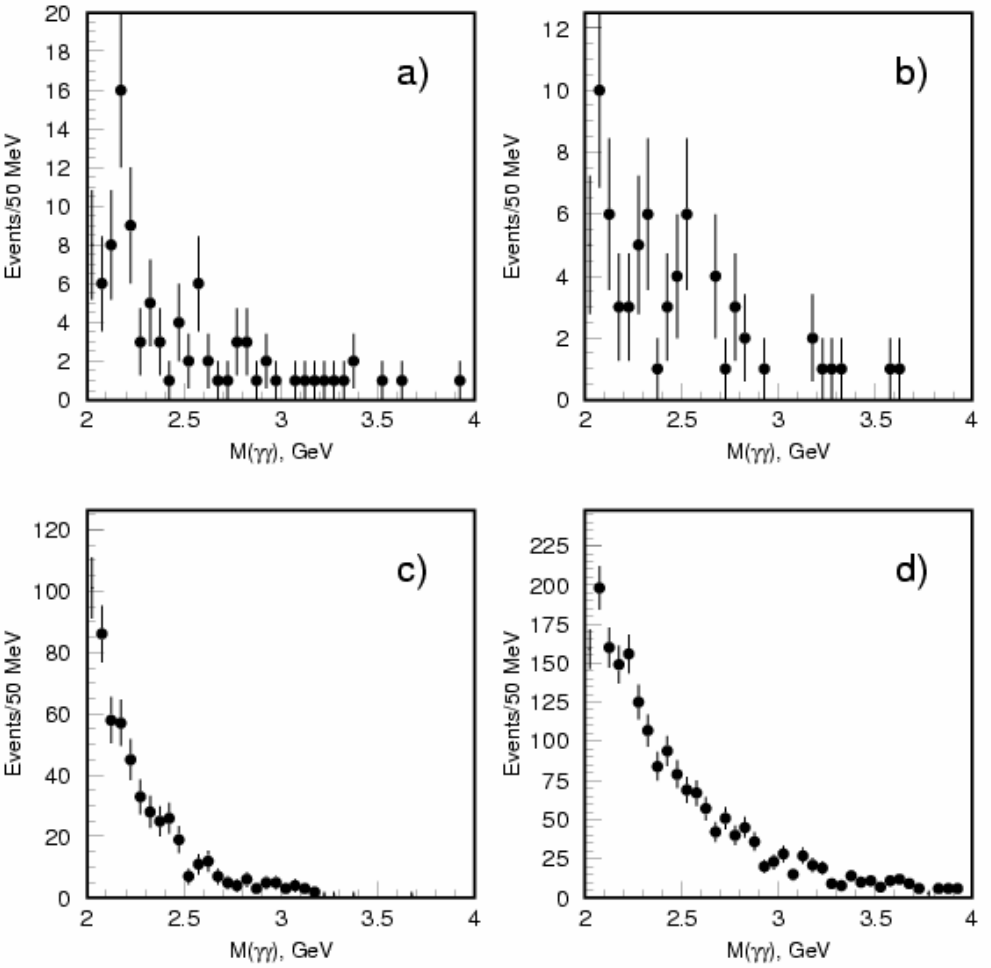
Nev=1+/-1

⇨c) $\gamma\gamma \rightarrow R \rightarrow \pi^+\pi^-\eta'(\rho^0\gamma)$

Nev=5+/-4

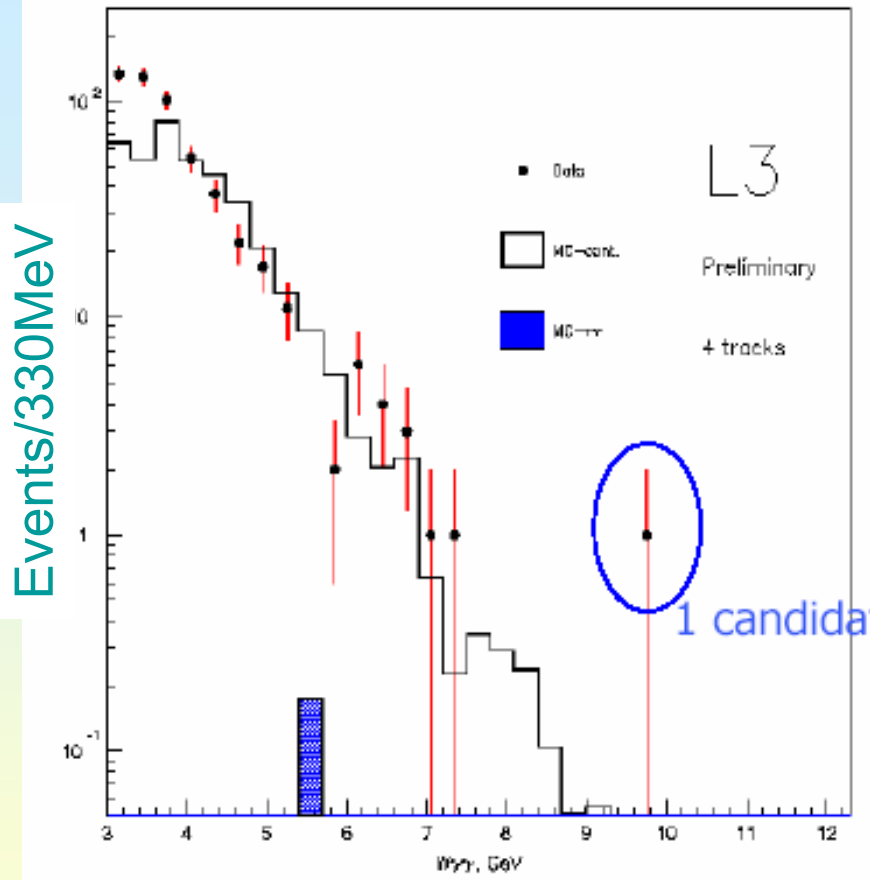
⇨d) $\gamma\gamma \rightarrow R \rightarrow \rho^+\rho^-$

Nev=8+/-5

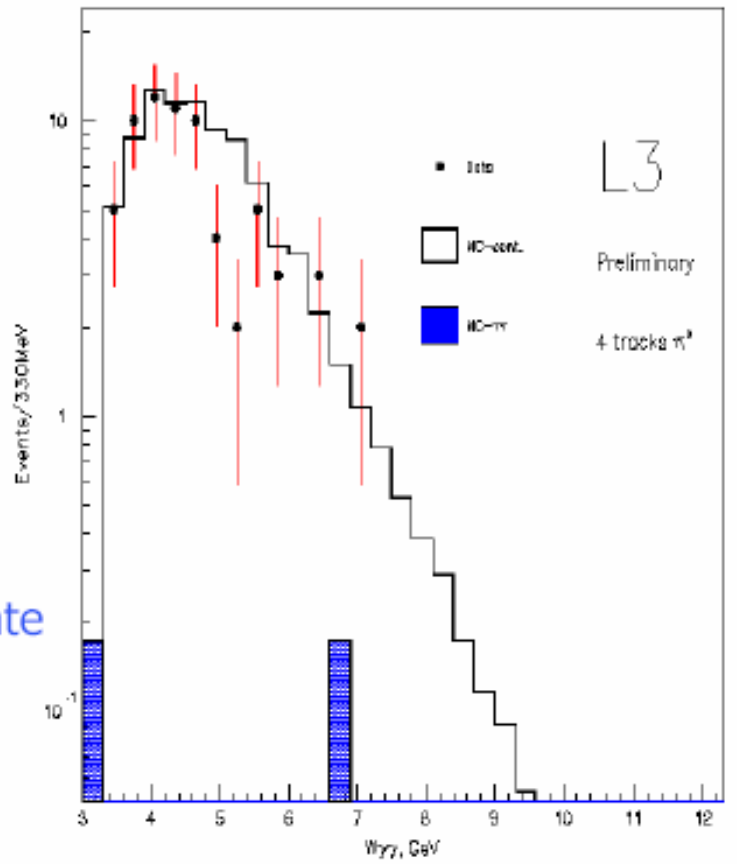


η_b

4 charged particles



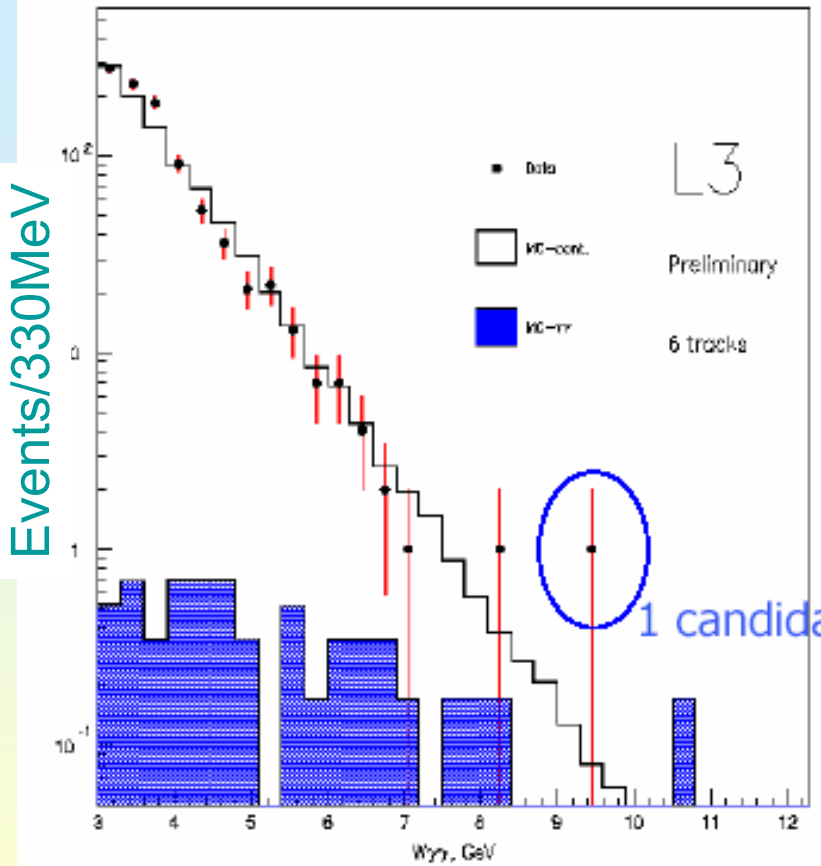
4 charged particles + π^0



⇨M=9.89+/-0.32 GeV

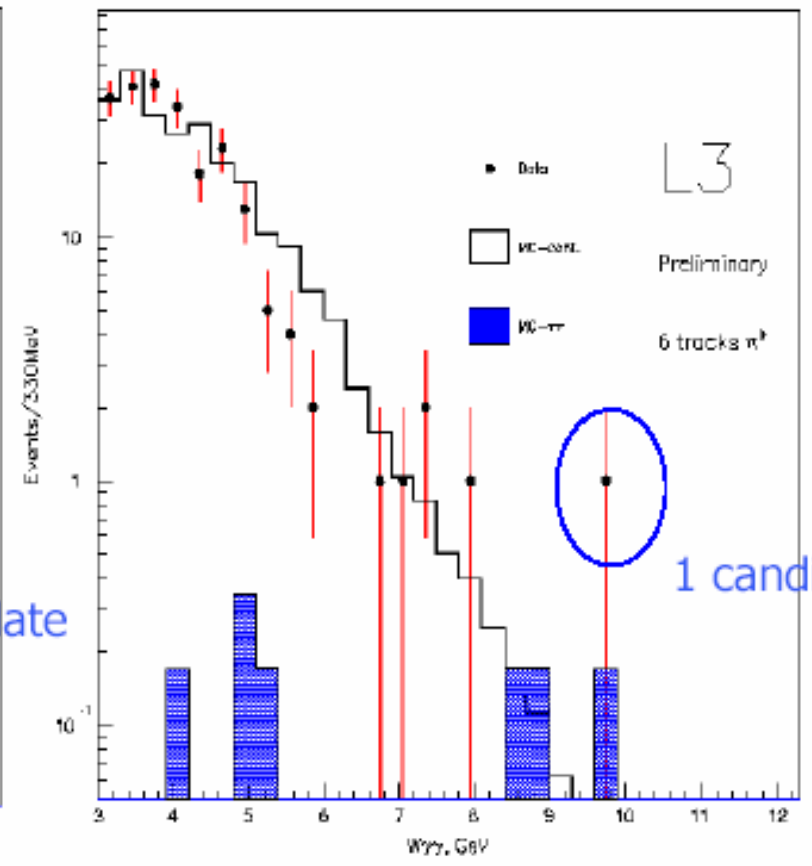
η_b

6 charged particles



⇨M=9.36 +/- 0.34GeV

6 charged particles + π^0



⇨M=9.89 +/-0.34GeV GeV

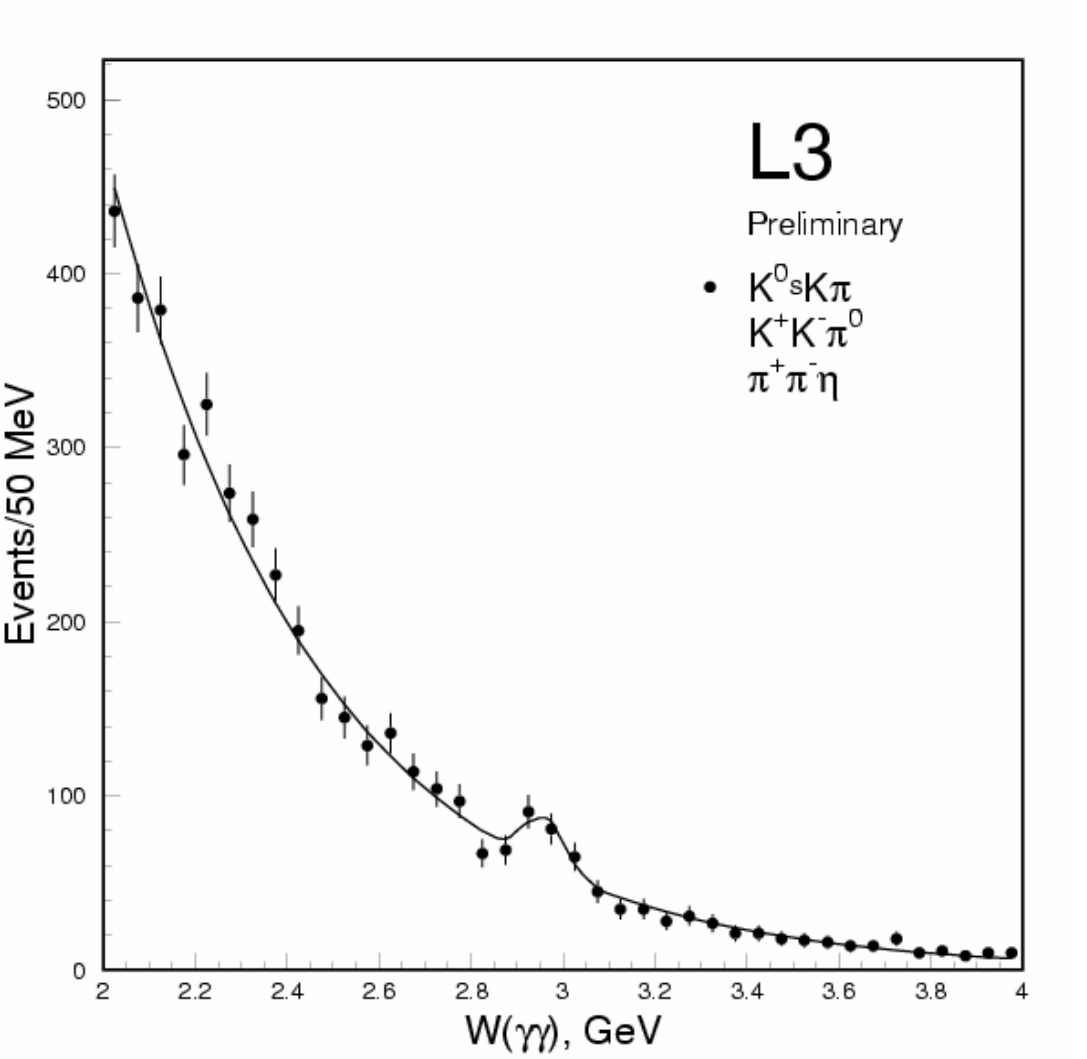
η_c - Sum

High energy Data(fit):

M(η_c)=2.965+/-0.017 GeV

Γ(η_c)=0.084+/-0.012 GeV

Nev=72+/-25



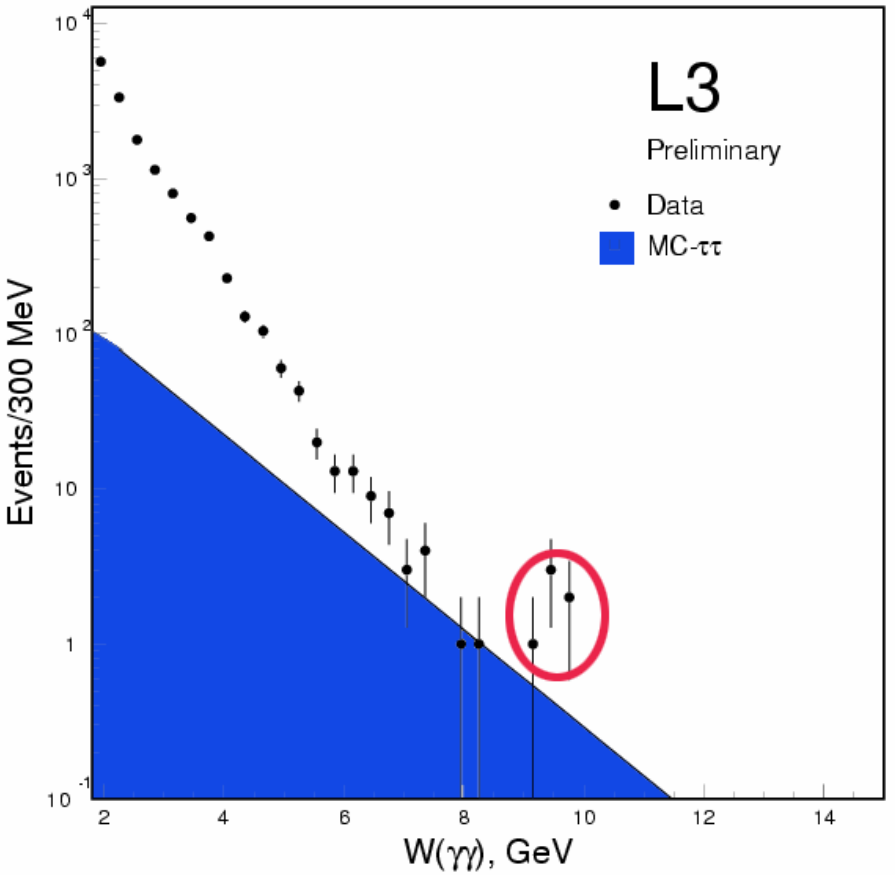
Summary on η_c

Channel	BR[%]	ε_{L3}[%]	$\Gamma_{\gamma\gamma}^{L3}$[keV]	ε[%]	$\Gamma_{\gamma\gamma}$[keV]	$N_e v$
$\eta_c \to 4\pi$	1.2	4.9/4.1	$< 28 / < 36$	4.43	—	—
$\eta_c \to 2\pi 2K$	2.0	5.2/4.5	$10 \pm 8 / 16 \pm 10$	2.52 ± 0.05	4.29 ± 1.43	30 ± 10
$\eta_c \to 4K$	2.1	—	—	1.50 ± 0.05	—	—
$\eta_c \to \pi^+\pi^-\eta(\gamma\gamma)$	1.3	3.3/3.9	$7.4^{+4.7}_{-4.4}$	5.42 ± 0.15	3.70 ± 1.06	35 ± 10
$\eta_c \to \pi^+\pi^-\eta(\pi^+\pi^-\pi^0)$	0.8	1.6/1.2	$< 16 / 15^{+18}_{-11}$	0.9	4.12 ± 3.04	4 ± 3
$\eta_c \to K^+K^-\pi^0$	0.9	2.6/3.3	$21^{+12}_{-11} / < 34$	3.68 ± 0.08	6.75 ± 3.37	30 ± 15
$\eta_c \to K_s^0 K^\pm \pi^\mp$	1.3	5.1/5.0	$5.4^{+3.9}_{-3.4} / 5.5^{+4.7}_{-3.9}$	2.23 ± 0.05	8.99 ± 3.08	35 ± 12
$\eta_c \to \rho^+\rho^-$	1.7	0.8/0.9	$< 28 / 24^{+21}_{-17}$	0.52 ± 0.03	6.73 ± 4.21	8 ± 5
$\eta_c \to \pi^+\pi^-\eta'(\rho^0\gamma)$	0.8	3.0/2.5	$16 \pm 10 / < 29$	0.41	11.42 ± 9.12	5 ± 4
$\eta_c \to \pi^+\pi^-\eta'(\pi^+\pi^-\eta)$	0.5	2.8/2.5	$7^{+7}_{-6} / < 32$	1.21	—	1

Table 2: η_c status after final selection.

Weighted average Γ=3.68±0.87(stat)±0.8(sys)±2.0(BR) keV
(Published:6.9±1.7(stat)±0.8(sys)±2.0(BR) keV)

η_b - Sum



Average effective mass: M = 9.51 ± 0.30 GeV*

N(candidates)=6, expected BG – 2.5

***Mass resolution due to detector effects ~ 300 MeV**

π/K misidentification ~ 50 MeV

Summary on η_b

- The observation is compatible with the background CL=4%

Upper limits on $\Gamma_{\gamma\gamma}(\eta_b)$xBR:

$\Gamma_{\gamma\gamma}(\eta_b)$xBR($K^+K^-\pi^0$)	<2.83 keV
$\Gamma_{\gamma\gamma}(\eta_b)$xBR(4 tracks)	<0.21 keV
$\Gamma_{\gamma\gamma}(\eta_b)$xBR(4 tracks π^0)	<0.50 keV
$\Gamma_{\gamma\gamma}(\eta_b)$xBR(6 tracks)	<0.33 keV
$\Gamma_{\gamma\gamma}(\eta_b)$xBR(6 tracks π^0)	<5.50 keV
$\Gamma_{\gamma\gamma}(\eta_b)$xBR($\pi^+\pi^-\eta'$)	<3.00 keV

At 95% of C.L.

Assuming the same BR for each channel:

$\Gamma_{\gamma\gamma}(\eta_b)$ x BR(all channels) < 0.2 keV at 95% of C.L.

Conclusion and Outlook

- ⇨New η_c results
  - ⇨Resonance parameters are measured with more precision
  - ⇨Two-photon width is calculated
- ⇨New η_b results
  - ⇨6 candidates of η_b are well measured and checked
  - ⇨Upper limit on two-photon width is given
- ⇨Both of analysis's are completed