η-η’: Experimental overview

Camilla Di Donato & Giulia Ricciardi
INFN-Napoli, Universita’ Federico II

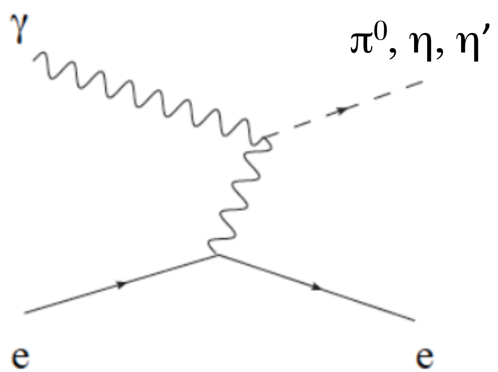
η-η’ widths measurement: γ–e Collider @IRIDE

- *Collider Modes for :*
  - e^- γ collisions for the precise measurement of the π^0 width through the process $e^- \gamma \rightarrow \pi^0 e^-$ (Primakoff effect),
  - $\gamma\,\gamma$ collisions for fundamental studies on QED, for example to observe and measure photon-photon scattering,
  - $e^+ e^-$ collision experiments up to 3 GeV energy in the center of mass

Sezione di Napoli

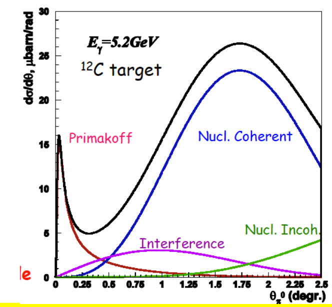
γ-e Linear Collider

- Among the large number of activities at IRIDE, we are interested to the fundamental physics investigations with low energy linear colliders



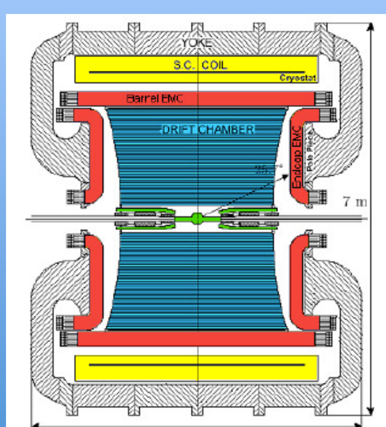
- Primakoff effekt: π, η, η'
- The photon-electron collision is a much cleaner environment compared to photon-nucleus case

$$\frac{d\sigma_{\mathrm{Pr}}}{d\Omega} = \Gamma_{\gamma\gamma} \frac{8\alpha Z^2}{m_\pi^3} \frac{\beta^3 E^4}{Q^4} \left|F_{e.m.}(Q)\right|^2 \sin^2\theta_\pi$$



KLOE/KLOE-2

ϕ-> η' γ
ϕ-> η γ



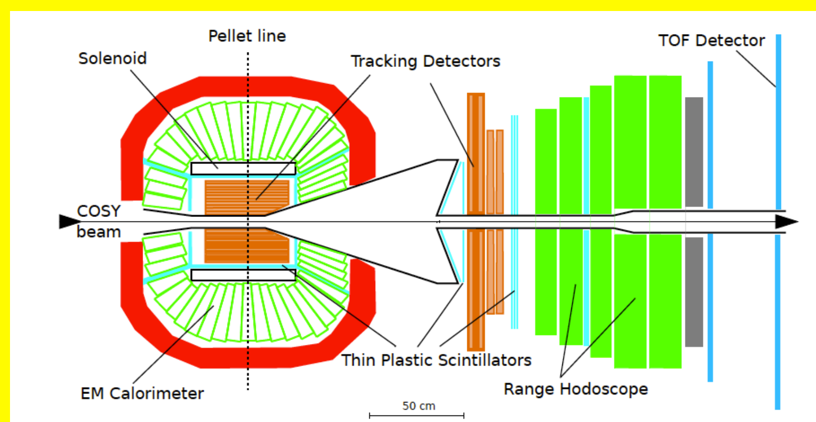
L_I= 5 fb^{-1}

$2*10^8$ η
$1*10^6$ η'

L_{II}= 20 fb^{-1}

WASA at COSY

pp->pp η
pd->^{3}He η



World Average from PDG, PR D86, 010001 (2012)

η WIDTH

This is the partial decay rate $\Gamma(\eta \to \gamma\gamma)$ divided by the fitted branching fraction for that mode. See the note at the start of the $\Gamma(2\gamma)$ data block, next below.

VALUE (keV)	*DOCUMENT ID*
1.30±0.07 OUR FIT	

Note on Decay width $\Gamma(\eta \to \gamma\gamma)$ by Roe [Phys. Rev. D 50, '94, p.1451]

η'(958) WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
0.199±0.009 OUR FIT						
0.230±0.021 OUR AVERAGE						
0.226±0.017±0.014	2300	CZERWINSKI	10	MMS		$pp \to pp\eta'$
0.40 ±0.22	4800	WURZINGER	96	SPEC		$1.68\ pd \to {}^3\mathrm{He}\,\eta'$
0.28 ±0.10	1000	BINNIE	79	MMS	0	$\pi^- p \to n\,\mathrm{MM}$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.20 ±0.04		BAI	04J	BES2		$J/\psi \to \gamma\gamma\pi^+\pi^-$

Direct measurement available: COSY-11 Facility

η: 1994 -> 2013

'94

η DECAY RATES

Γ(2γ) Γ_2

See the "Note on the Decay Width Γ(η → γγ)," below.

VALUE (keV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.46 ±0.04 OUR FIT	Error includes scale factor of 1.8.				
0.46 ±0.04 OUR AVERAGE	Error includes scale factor of 1.8. See the ideogram below.				
0.51 ±0.12 ±0.05	36	BARU	90	MD1	$e^+e^- \to e^+e^-\eta$
0.490±0.010±0.048	2287	ROE	90	ASP	$e^+e^- \to e^+e^-\eta$
0.514±0.017±0.035	1295	WILLIAMS	88	CBAL	$e^+e^- \to e^+e^-\eta$
0.53 ±0.04 ±0.04		BARTEL	85E	JADE	$e^+e^- \to e^+e^-\eta$
0.324±0.046		BROWMAN	74B	CNTR	Primakoff effect
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.64 ±0.14 ±0.13		AIHARA	86	TPC	$e^+e^- \to e^+e^-\eta$
0.56 ±0.16	56	WEINSTEIN	83	CBAL	$e^+e^- \to e^+e^-\eta$
1.00 ±0.22		[1] BEMPORAD	67	CNTR	Primakoff effect

[1] BEMPORAD 67 gives Γ(2γ) = 1.21 ± 0.26 keV assuming Γ(2γ)/Γ(total) = 0.314. Bemporad private communication gives $\Gamma(2\gamma)^2/\Gamma(\text{total}) = 0.380 \pm 0.083$. We evaluate this using Γ(2γ)/Γ(total) = 0.38 ± 0.01. Not included in average because the uncertainty resulting from the separation of the coulomb and nuclear amplitudes has apparently been underestimated.

NOTE ON THE DECAY WIDTH Γ(η → γγ)

(by N.A. Roe, Lawrence Berkeley Laboratory)

In the measurements of Γ(η → γγ) listed below, the results from two-photon production disagree with those from Primakoff production. Since the 1990 edition, one new two-photon measurement has been reported by MD-1; it is consistent with previous two-photon results, though the errors are somewhat larger. The weighted average of the two-photon measurements is 0.510 ± 0.026 keV, to be compared with the Primakoff-production measurement of BROWMAN 74B, 0.324 ± 0.046 keV.

A. Sibirtsev EPJ

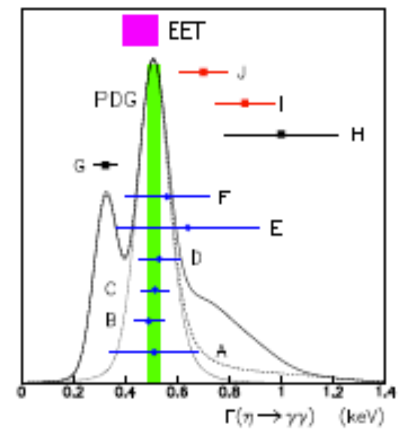


Fig. 5. The η→γγ radiative decay width from different analyses. The results are taken from: A [13], B [14], C [15], D [16], E [17], F [18], G [19], H [20]. Our own results obtained from a fit of the γp→ηp differential cross sections [26,23] at the photon energies of 4 and 6 GeV, are denoted by I and J, respectively. Circles are data obtained from the $e^+e^-\to e^+e^-\eta$ reaction, while squares indicate results obtained by Primakoff-effect measurements. The shaded box, indicated as PDG, is an averaged result [12]. The box indicated as EET shows the limit given by Eq. (2). The lines indicate data distribution functions as explained in the text.

η: 1994 -> 2013

‘94

η DECAY RATES

Γ(2γ)

See the “Note on the Decay Width Γ(η

VALUE (keV)			*EVTS*	*DOCUMEN*
0.46	**±0.04**	**OUR FIT**	Error includes scale f	
0.46	**±0.04**	**OUR AVERAGE**	Error includes	
0.51	±0.12	±0.05	36	BARU
0.490	±0.010	±0.048	2287	ROE
0.514	±0.017	±0.035	1295	WILLIAN
0.53	±0.04	±0.04		BARTEL
0.324	±0.046			BROWM

• • • We do not use the following data for av

0.64	±0.14	±0.13		AIHARA
0.56	±0.16		56	WEINST
1.00	±0.22			[1] BEMPOI

[1] BEMPORAD 67 gives Γ(2γ) = 1.21 ± 0.
Bemporad private communication gives Γ(2
this using Γ(2γ)/Γ(total) = 0.38 ± 0.01. No
resulting from the separation of the coulomb
underestimated.

η DECAY RATES ‘13

Γ(2γ) Γ_2

See the table immediately above giving the fitted decay rates. Following the advice of NEFKENS 02, we have removed the Primakoff-effect measurement from the average. See also the “Note on the Decay Width Γ(η → γγ),” in our 1994 edition, Phys. Rev. **D50**, 1 August 1994, Part I, p. 1451, for a discussion of the various measurements.

VALUE (keV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.510±0.026 OUR FIT					
0.510±0.026 OUR AVERAGE					
0.51 ±0.12 ±0.05	36	BARU	90	MD1	$e^+e^- \to e^+e^-\eta$
0.490±0.010±0.048	2287	ROE	90	ASP	$e^+e^- \to e^+e^-\eta$
0.514±0.017±0.035	1295	WILLIAMS	88	CBAL	$e^+e^- \to e^+e^-\eta$
0.53 ±0.04 ±0.04		BARTEL	85E	JADE	$e^+e^- \to e^+e^-\eta$

• • • We do not use the following data for averages, fits, limits, etc. • • •

0.476±0.062		[2] RODRIGUES	08	CNTR	Reanalysis
0.64 ±0.14 ±0.13		AIHARA	86	TPC	$e^+e^- \to e^+e^-\eta$
0.56 ±0.16	56	WEINSTEIN	83	CBAL	$e^+e^- \to e^+e^-\eta$
0.324±0.046		BROWMAN	74B	CNTR	Primakoff effect
1.00 ±0.22		[3] BEMPORAD	67	CNTR	Primakoff effect

[2] RODRIGUES 08 uses a more sophisticated calculation for the inelastic background due to incoherent photoproduction to reanalyze the η photoproduction data on Be and Cu at 9 GeV from BROWMAN 74B. This brings the value of Γ(η → 2γ) in line with direct measurements of the width. The error here is only statistical.

[3] BEMPORAD 67 gives Γ(2γ) = 1.21 ± 0.26 keV assuming Γ(2γ)/Γ(total) = 0.314. Bemporad private communication gives $\Gamma(2\gamma)^2/\Gamma(\text{total}) = 0.380 \pm 0.083$. We evaluate this using Γ(2γ)/Γ(total) = 0.38 ± 0.01. Not included in average because the uncertainty resulting from the separation of the coulomb and nuclear amplitudes has apparently been underestimated.

η: 1994 -> 2013

'94

η DECAY RATES

Γ(2γ)

See the "Note on the Decay Width Γ(η

VALUE (keV)			EVTS	DOCUMEN
0.46	**±0.04**	**OUR FIT**	Error includes scale f	
0.46	**±0.04**	**OUR AVERAGE**	Error includes	
0.51	±0.12	±0.05	36	BARU
0.490	±0.010	±0.048	2287	ROE
0.514	±0.017	±0.035	1295	WILLIAN
0.53	±0.04	±0.04		BARTEL
0.324	±0.046			BROWM
• • • We do not use the following data for av				
0.64	±0.14	±0.13		AIHARA
0.56	±0.16		56	WEINST
1.00	±0.22			[1] BEMPOI

[1] BEMPORAD 67 gives Γ(2γ) = 1.21 ± 0.
Bemporad private communication gives Γ(2
this using Γ(2γ)/Γ(total) = 0.38 ± 0.01. No
resulting from the separation of the coulomb
underestimated.

@ IRIDE: Primakoff effect γ-e
No background due to incoherent
Photoproduction:

Cross-section production should
be evaluated

η DECAY RATES

'13

Γ(2γ) Γ_2

See the table immediately above giving the fitted decay rates. Following the advice of NEFKENS 02, we have removed the Primakoff-effect measurement from the average. See also the "Note on the Decay Width Γ(η → γγ)," in our 1994 edition, Phys. Rev. **D50**, 1 August 1994, Part I, p. 1451, for a discussion of the various measurements.

VALUE (keV)	EVTS	DOCUMENT ID		TECN	COMMENT
0.510±0.026 OUR FIT					
0.510±0.026 OUR AVERAGE					
0.51 ±0.12 ±0.05	36	BARU	90	MD1	$e^+e^- \rightarrow e^+e^-\eta$
0.490±0.010±0.048	2287	ROE	90	ASP	$e^+e^- \rightarrow e^+e^-\eta$
0.514±0.017±0.035	1295	WILLIAMS	88	CBAL	$e^+e^- \rightarrow e^+e^-\eta$
0.53 ±0.04 ±0.04		BARTEL	85E	JADE	$e^+e^- \rightarrow e^+e^-\eta$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.476±0.062		[2] RODRIGUES	08	CNTR	Reanalysis
0.64 ±0.14 ±0.13		AIHARA	86	TPC	$e^+e^- \rightarrow e^+e^-\eta$
0.56 ±0.16	56	WEINSTEIN	83	CBAL	$e^+e^- \rightarrow e^+e^-\eta$
0.324±0.046		BROWMAN	74B	CNTR	Primakoff effect
1.00 ±0.22		[3] BEMPORAD	67	CNTR	Primakoff effect

[2] RODRIGUES 08 uses a more sophisticated calculation for the inelastic background due to incoherent photoproduction to reanalyze the η photoproduction data on Be and Cu at 9 GeV from BROWMAN 74B. This brings the value of Γ(η → 2γ) in line with direct measurements of the width. The error here is only statistical.

[3] BEMPORAD 67 gives Γ(2γ) = 1.21 ± 0.26 keV assuming Γ(2γ)/Γ(total) = 0.314. Bemporad private communication gives $\Gamma(2\gamma)^2/\Gamma(\text{total}) = 0.380 \pm 0.083$. We evaluate this using Γ(2γ)/Γ(total) = 0.38 ± 0.01. Not included in average because the uncertainty resulting from the separation of the coulomb and nuclear amplitudes has apparently been underestimated.

World Average from PDG, PR D86, 010001 (2012)

η WIDTH

This is the partial decay rate $\Gamma(\eta \to \gamma\gamma)$ divided by the fitted branching fraction for that mode. See the note at the start of the $\Gamma(2\gamma)$ data block, next below.

VALUE (keV)	*DOCUMENT ID*
1.30±0.07 OUR FIT	

Note on Decay width $\Gamma(\eta\text{->}\gamma\gamma)$ by Roe [Phys. Rev. D 50, '94, p.1451]

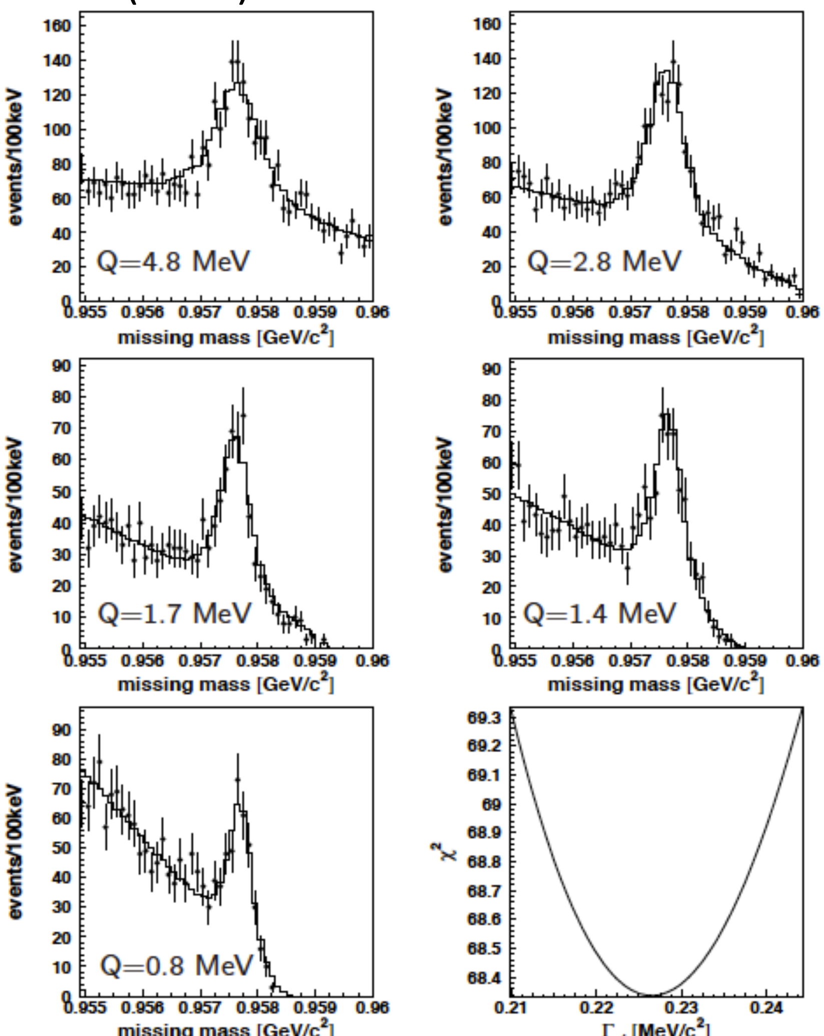
η'(958) WIDTH

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
0.199±0.009 OUR FIT						
0.230±0.021 OUR AVERAGE						
0.226±0.017±0.014	2300	CZERWINSKI	10	MMS		$pp \to pp\eta'$
0.40 ±0.22	4800	WURZINGER	96	SPEC		$1.68\ pd \to {}^3\text{He}\eta'$
0.28 ±0.10	1000	BINNIE	79	MMS	0	$\pi^- p \to n\text{MM}$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
0.20 ±0.04		BAI	04J	BES2		$J/\psi \to \gamma\gamma\pi^+\pi^-$

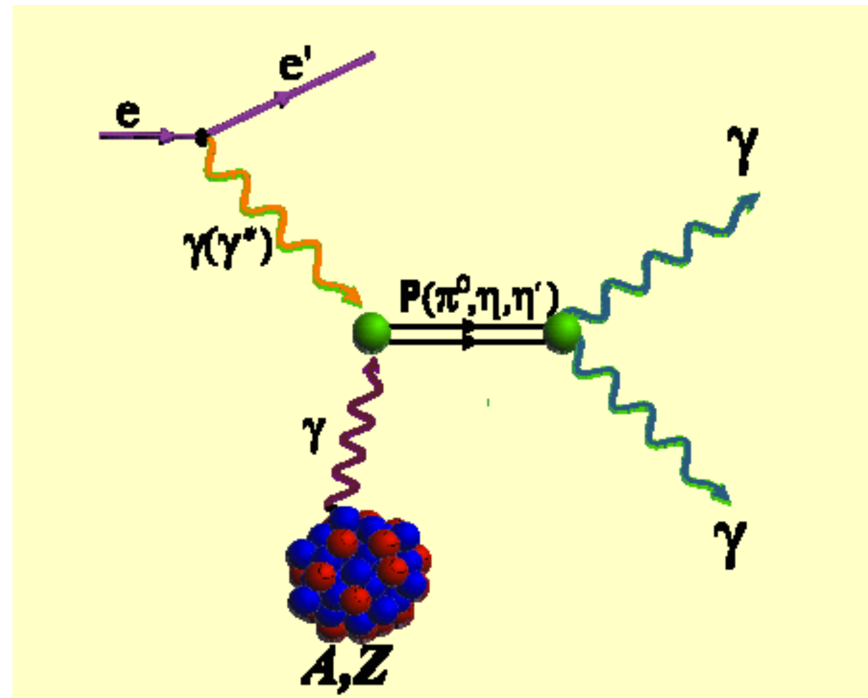
Direct measurement available: COSY-11 Facility

Γ Measurements

COSY11 Facility $\Gamma\eta'$ measurement: pp -> ppX
PRL 105 (2010) 122001



Primakoff Program @ JLab. [Primex @ Gluex, L. Gan, APS April Meeting 2013]



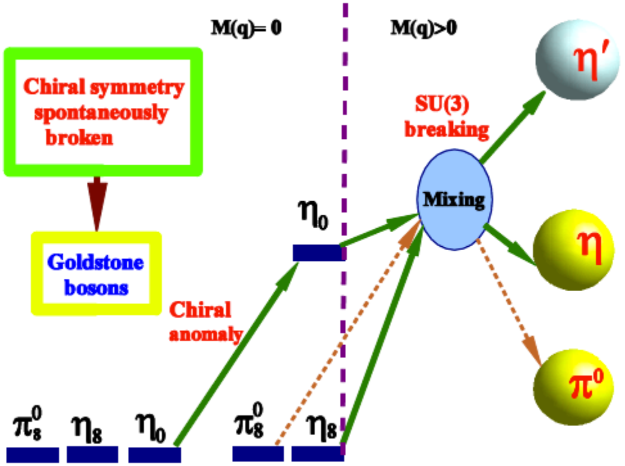
Precision measurements of electromagnetic properties of π^0, η, η' via Primakoff effect.

Impact

Accuracy on Γ_η and $\Gamma_{\eta'}$ limits investigations on many issues:

- Quark mass difference
- Isospin breaking in QCD, η-η' mixing
- Chiral Anomalies, $\Gamma(\pi^0/\eta/\eta' \to \gamma\gamma)$, $\Gamma(\eta/\eta' \to \pi\pi\gamma)$

The system of π^0, η, η' mesons as a laboratory to study symmetry structure of QCD al low energies



L. Gan, APS April Meeting 2013

Quark Mass Difference

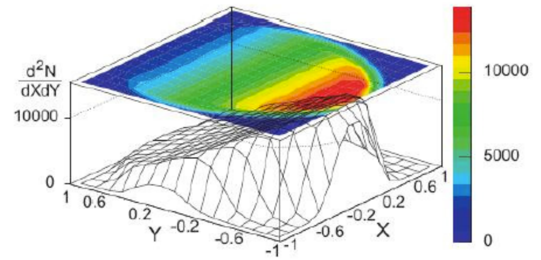
Determine light quark mass ratio: from $\eta \to 3\pi$
Decay width Γ_i disagree between experimental and χPT
$\Gamma_{i(LO)}$=40 eV; $\Gamma_{i(NLO)}$=160±50 eV; $\Gamma_{i(EXP)}$=295±16 eV

$$\Gamma(\eta \to 3\pi) \propto |A|^2 \propto Q^{-4}$$

$$A(s,t,u) = \frac{1}{Q^2}\frac{m_K^2}{m_\pi^2}\left(m_\pi^2 - m_K^2\right)\frac{M(s,t,u)}{s\sqrt{3}F_\pi^2}$$

$$Q^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$$

KLOE JHEP05 (2008)006:
Dynamics of $\eta \to 3\pi$
Fit to Dalitz plot to measure slope parameters.



Width measurement: $\Gamma(\eta \to 3\pi) = \Gamma_\eta \times BR$

Mixing η−η’ and gluonium

Constraint also from: Γ(η’->γγ)/Γ(η->γγ)

- KLOE analysis [PLB 648 (2007) 267–273; JHEP07(2009)105]
- R. Escribano and J. Nadal, JHEP05 (2007) 006.
- C. E. Thomas, JHEP10 (2007) 026.
- C. Di Donato, G. Ricciardi and I. I. Bigi, PRD 85, 013016 (2012)

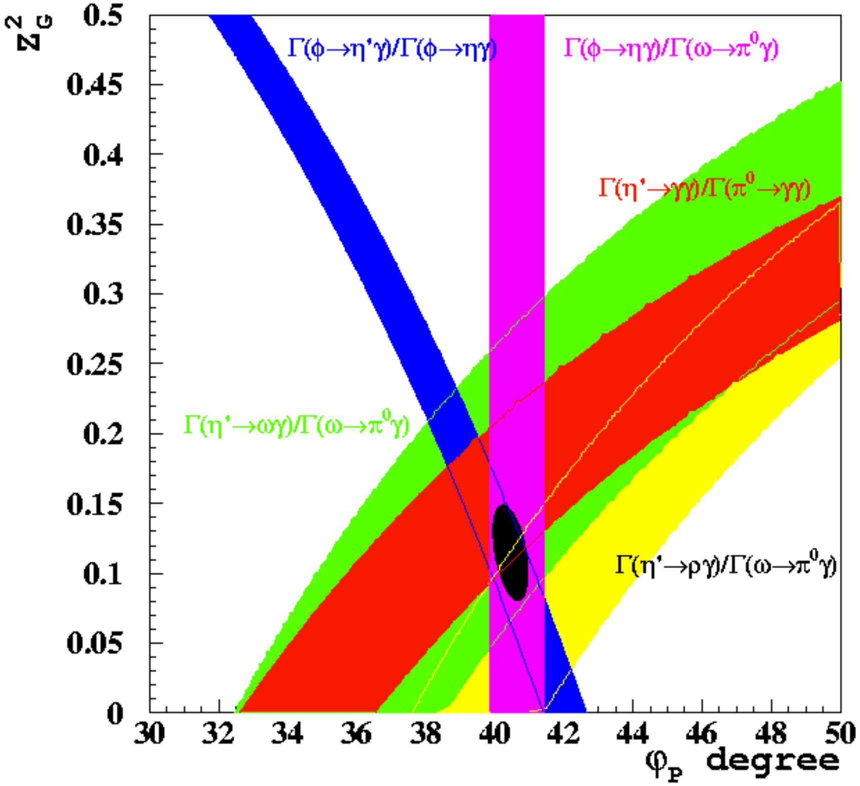
TABLE III. I: widths from PDG 2010 fits; II: errors on $\eta' \to \omega\gamma$ reduced; III: errors on $\eta' \to \rho\gamma$ reduced; IV: errors on $\phi \to \eta^{(\prime)}\gamma$ reduced; V: reducing the uncertainties for all partial widths; VI: all recalculated in the hypothesis of 1.4% for the η' full width.

Processes	$(\delta\Gamma/\Gamma)_I$	$(\delta\Gamma/\Gamma)_{II}$	$(\delta\Gamma/\Gamma)_{III}$	$(\delta\Gamma/\Gamma)_{IV}$	$(\delta\Gamma/\Gamma)_V$	$(\delta\Gamma/\Gamma)_{VI}$
$\phi \to \eta'\gamma$	3.5%	3.5%	3.5%	1.7%	1.7%	1%
$\phi \to \eta\gamma$	2%	2%	2%	1%	1%	2%
$\eta' \to \omega\gamma$	9%	4.5%	9%	9%	4.5%	1.7%
$\eta' \to \rho\gamma$	5%	5%	2.5%	5%	2.5%	1.7%
$\rho \to \eta\gamma$	7%	7%	7%	7%	3.4%	7%
$\omega \to \eta\gamma$	9%	9%	9%	9%	4.5%	9%
ϕ_P	$(40.6 \pm 0.9)°$	$(40.1^{+0.8}_{-1.0})°$	$(40.7 \pm 0.7)°$	$(40.6^{+0.5}_{-0.6})°$	$(40.4 \pm 0.5)°$	$(40.1 \pm 0.3)°$
$Z^2_{\eta'}$	(0.09 ± 0.05)	(0.13 ± 0.05)	(0.08 ± 0.04)	(0.09 ± 0.03)	(0.10 ± 0.03)	(0.13 ± 0.02)

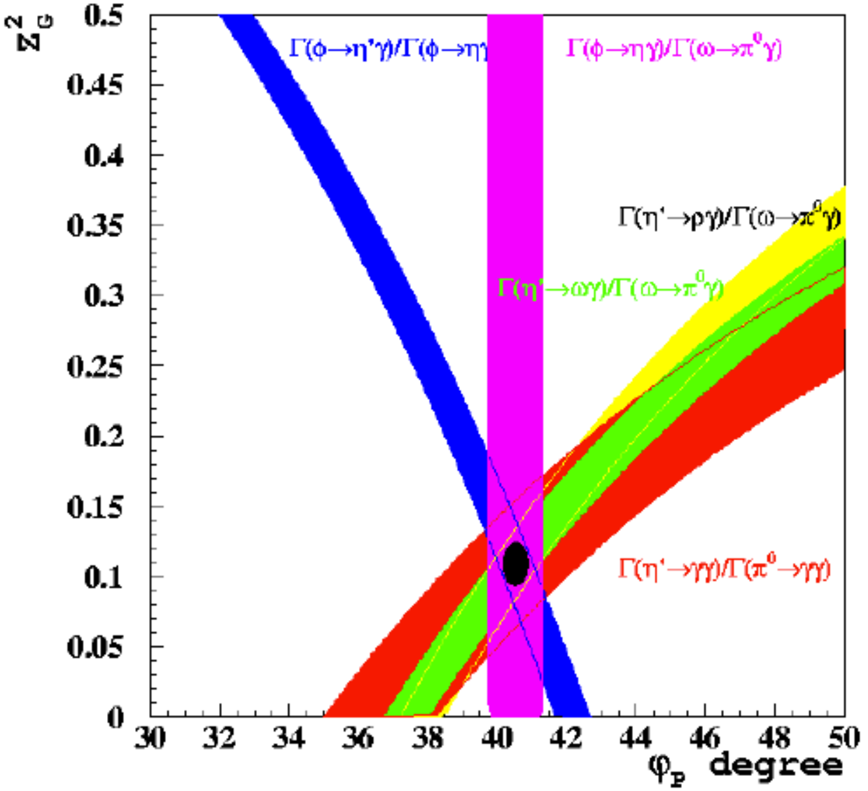
PRD85

η' Gluonium VS η-η' Mixing

KLOE: JHEP07(2009)105



KLOE2: Run at √s≥1.2 GeV



Anomaly

- Box Anomaly: η, $\eta' \to \pi+\pi-\gamma$ are expected to get contribution from anomaly, Wess Zumino Witten term in ChPT Lagrangian
- According to Effective Theory [HLS: Benayoun, Eur. Phys. J. C31 (2003) 525], they could be described by VMD + a direct term
- Model independent method based on ChPT and dispersive analysis: do not fix relative strength between tree level contribution and resonance contribution [Stollenwerk, Hanhart, Kupsc, Meißner and Wirzba PLB707 (2012) 184-190]

$\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ — **Γ_{10}/Γ_9**

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.202±0.007 OUR FIT Error includes scale factor of 2.4.					
0.203±0.008 OUR AVERAGE Error includes scale factor of 2.4. See the ideogram below.					
0.175±0.007±0.006	859	LOPEZ	07	CLEO	$\psi(2S) \to J/\psi\eta$
0.209±0.004	18k	THALER	73	ASPK	
0.201±0.006	7250	GORMLEY	70	ASPK	

Theory HLS-Model:
$\Gamma(\eta\to\pi+\pi-\gamma)$w = (56.3±1.7) eV , $\Gamma(\eta\to\pi+\pi-\gamma)$wo = (100.9±2.8) eV

KLOE/KLOE2:
$\Gamma(\eta\to\pi+\pi-\gamma)$ = (54.7±3.1) eV [PLB 718 (2013) 910–914]

Anomaly

[KLOE/KLOE2PLB 718 (2013) 910–914]

[WASA Coll. PLB707 (2012) 243-249]

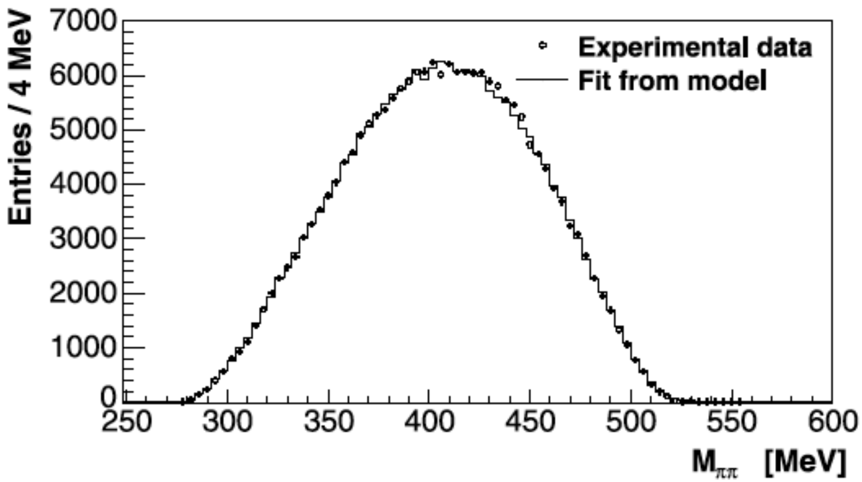


Fig. 4. Distribution of $M_{\pi\pi}$ after background subtraction (black markers). Histogram is the fit of Eq. (1), corrected for acceptance and experimental resolution.

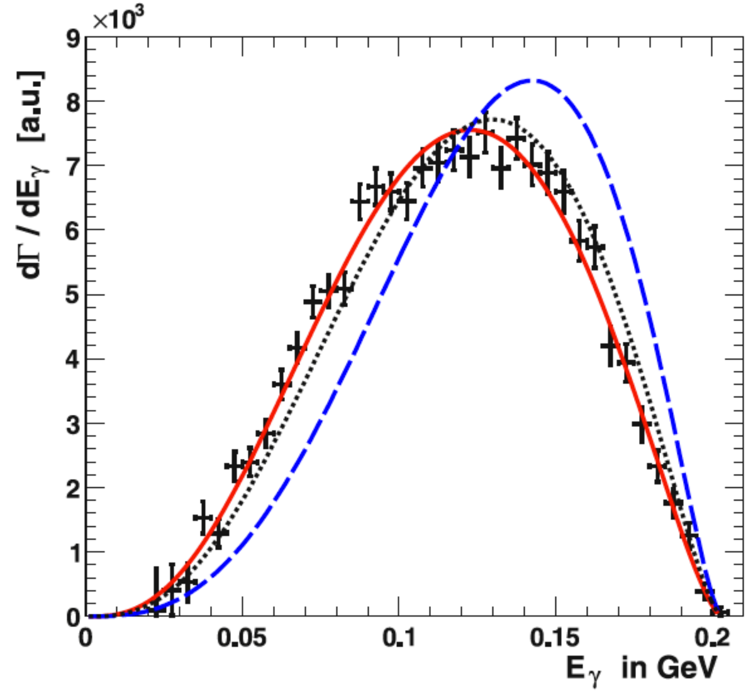
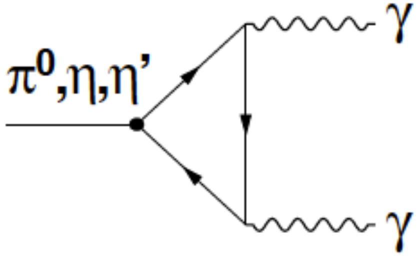
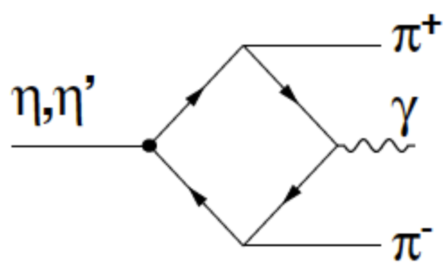


Fig. 6. The background subtracted and acceptance corrected angular distribution of the pions (top) and the photon energy distribution (bottom), with error bars indicating the statistical uncertainties. The angular distribution is compared with a relative p-wave of the pions (dashed curve). The shape of the photon energy distribution is confronted with predictions of the square of the simplest gauge invariant matrix element, Eq. (2) (dashed curve), multiplied by the squared modulus of the pion vector form factor $|F_V(s_{\pi\pi})|^2$ (dotted curve) and further multiplied by $(1+\alpha s_{\pi\pi})^2$, the square of a real polynomial of first order, with its coefficient fitted to the data (solid curve). All curves are normalized to the same integral.





Remarks & Outlooks

- The system of π^0, η, η' mesons as a laboratory to study symmetry structure of QCD al low energies
- New measurement of Γ_η and $\Gamma_{\eta'}$ will impact on many issues:
  - Quark mass difference
  - Isospin breaking in QCD, η-η' mixing
  - Chiral Anomalies

Remarks & Outlooks

- IRIDE could also look for f_0 and a_0 mesons
- Search of exotic state