

η - η' : Experimental overview

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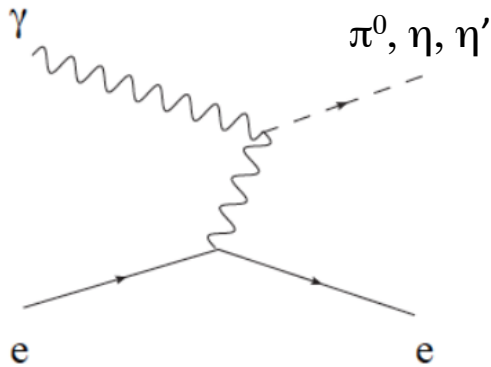
η - η' widths measurement: γ -e Collider @IRIDE

- *Collider Modes for :*
 - $e^- \gamma$ 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



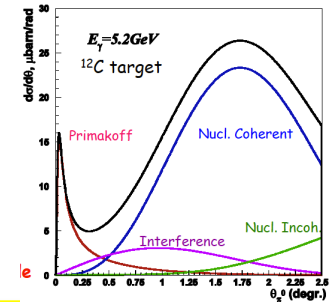
γ -e Linear Collider

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

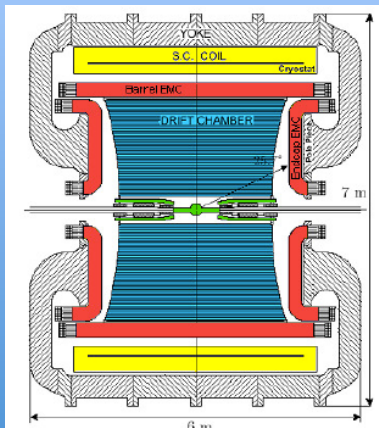


- Primakoff effect: π, η, η'
- The photon-electron collision is a much cleaner environment compared to photon-nucleus case

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



KLOE/KLOE-2



$\phi \rightarrow \eta' \gamma$
 $\phi \rightarrow \eta \gamma$

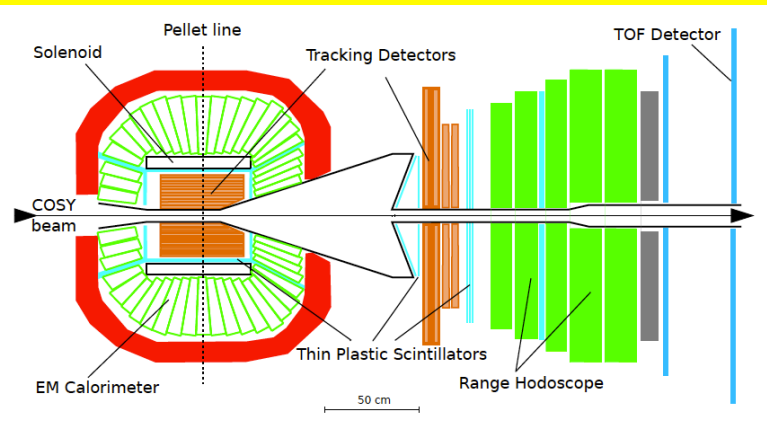
$L_{\int} = 5 \text{ fb}^{-1}$

$2 \cdot 10^8 \eta$

$1 \cdot 10^6 \eta'$

$L_{\int} = 20 \text{ fb}^{-1}$

WASA at COSY



$pp \rightarrow pp \eta$
 $pd \rightarrow {}^3\text{He} \eta$

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

η WIDTH

This is the partial decay rate $\Gamma(\eta \rightarrow \gamma\gamma)$ 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 $\Gamma(\eta \rightarrow \gamma\gamma)$ by Roe [Phys. Rev. D 50, '94, p.1451]

$\eta'(958)$ 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

$pp \rightarrow pp\eta'$

0.40 ± 0.22

4800

WURZINGER 96

SPEC

1.68 $pd \rightarrow {}^3\text{He}\eta'$

0.28 ± 0.10

1000

BINNIE 79

MMS

0

$\pi^- p \rightarrow nMM$

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

0.20 ± 0.04

BAI

04J

BES2

$J/\psi \rightarrow \gamma\gamma\pi^+\pi^-$

Direct measurement available: COSY-11 Facility

η : 1994 -> 2013

'94

η DECAY RATES

$\Gamma(2\gamma)$

Γ_2

See the "Note on the Decay Width $\Gamma(\eta \rightarrow \gamma\gamma)$," 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	$e^+e^- \rightarrow e^+e^-\eta$
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	$e^+e^- \rightarrow e^+e^-\eta$
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	$e^+e^- \rightarrow e^+e^-\eta$
0.56 ± 0.16	56	WEINSTEIN	83 CBAL	$e^+e^- \rightarrow e^+e^-\eta$
1.00 ± 0.22		¹ BEMPORAD	67 CNTR	Primakoff effect

¹ BEMPORAD 67 gives $\Gamma(2\gamma) = 1.21 \pm 0.26$ keV assuming $\Gamma(2\gamma)/\Gamma(\text{total}) = 0.314$.

Bemporad private communication gives $\Gamma(2\gamma)^2/\Gamma(\text{total}) = 0.380 \pm 0.083$. We evaluate this using $\Gamma(2\gamma)/\Gamma(\text{total}) = 0.38 \pm 0.01$. 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 $\Gamma(\eta \rightarrow \gamma\gamma)$

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

In the measurements of $\Gamma(\eta \rightarrow \gamma\gamma)$ 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.

η : 1994 -> 2013

'94

η DECAY RATES

$\Gamma(2\gamma)$

See the "Note on the Decay Width $\Gamma(\eta$

VALUE (keV) EVTS DOCUMENT

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0.46 ± 0.04 OUR AVERAGE Error includes

0.51 ± 0.12 ± 0.05	36	BARU
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Bemporad private communication gives $\Gamma(2\gamma)$ this using $\Gamma(2\gamma)/\Gamma(\text{total}) = 0.38 \pm 0.01$. No resulting from the separation of the coulomb underestimated.

'13

η DECAY RATES

$\Gamma(2\gamma)$

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 $\Gamma(\eta \rightarrow \gamma\gamma)$," in our 1994 edition, Phys. Rev. **D50**, 1 August 1994, Part I, p. 1451, for a discussion of the various measurements.

Γ_2

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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	$e^+e^- \rightarrow e^+e^-\eta$
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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 $\Gamma(\eta \rightarrow 2\gamma)$ in line with direct measurements of the width. The error here is only statistical.

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Bemporad private communication gives $\Gamma(2\gamma)$ this using $\Gamma(2\gamma)/\Gamma(\text{total}) = 0.38 \pm 0.01$. No background due to incoherent photoproduction: underestimated.

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

Cross-section production should
 be evaluated

η DECAY RATES

'13

$\Gamma(2\gamma)$

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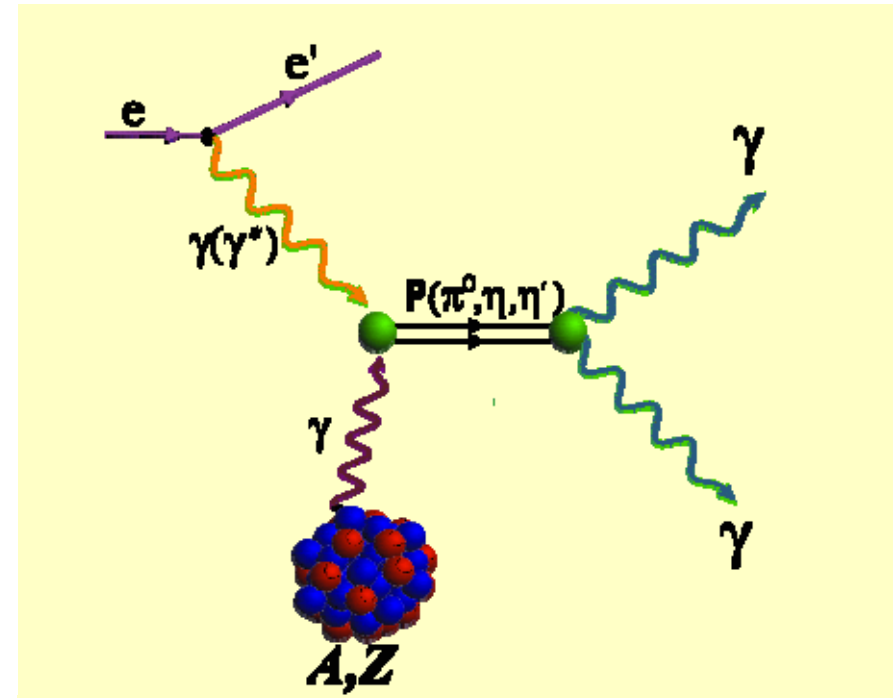
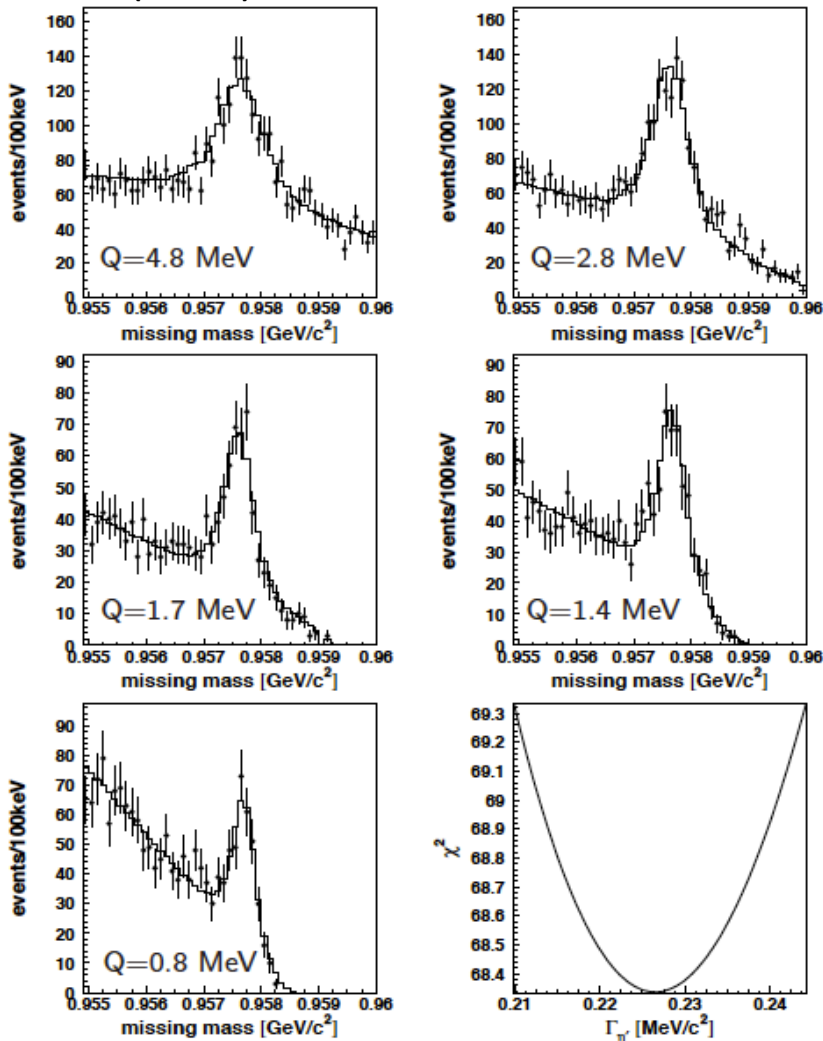
$J/\psi \rightarrow \gamma\gamma\pi^+\pi^-$

Direct measurement available: COSY-11 Facility

Γ Measurements

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

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



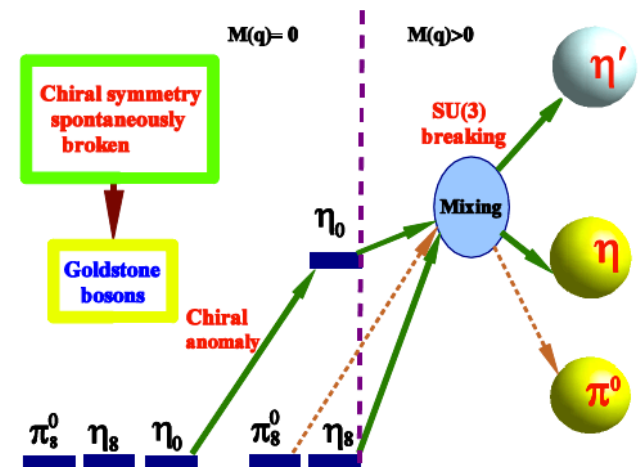
Precision measurements of
 electromagnetic properties
 of π^0, η, η' via Primakoff
 effect.

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, $\Gamma(\pi^0/\eta/\eta' \rightarrow \gamma\gamma)$, $\Gamma(\eta/\eta' \rightarrow \pi\pi\gamma)$

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



Quark Mass Difference

Determine light quark mass ratio: from $\eta \rightarrow 3\pi$

Decay width Γ_i disagree between experimental and χ PT

$\Gamma_{i(\text{LO})} = 40 \text{ eV}$; $\Gamma_{i(\text{NLO})} = 160 \pm 50 \text{ eV}$; $\Gamma_{i(\text{EXP})} = 295 \pm 16 \text{ eV}$

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

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

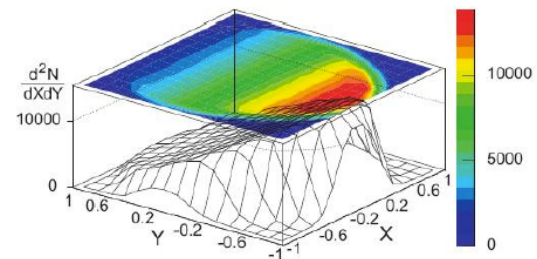
$$Q^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$$

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

KLOE JHEP05 (2008)006:

Dynamics of $\eta \rightarrow 3\pi$

Fit to Dalitz plot to measure slope parameters.



Mixing η - η' and gluonium

Constraint also from:
 $\Gamma(\eta' \rightarrow \gamma\gamma)/\Gamma(\eta \rightarrow \gamma\gamma)$

- 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)

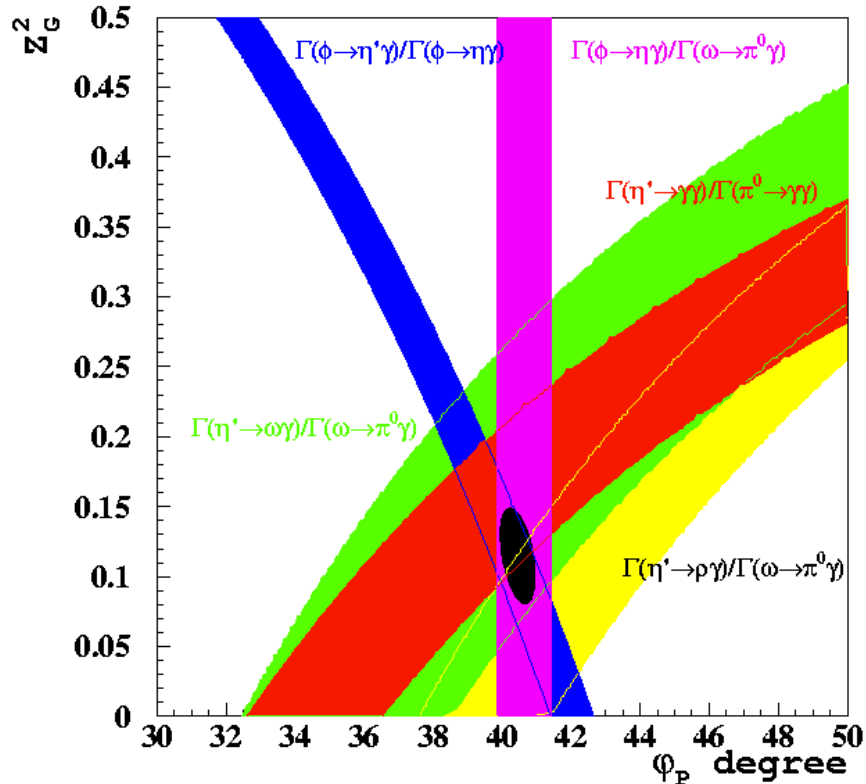
TABLE III. I: widths from PDG 2010 fits; II: errors on $\eta' \rightarrow \omega\gamma$ reduced; III: errors on $\eta' \rightarrow \rho\gamma$ reduced; IV: errors on $\phi \rightarrow \eta^{(i)}\gamma$ reduced; V: reducing the uncertainties for all partial widths; VI: all recalculated in the hypothesis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

PRD85

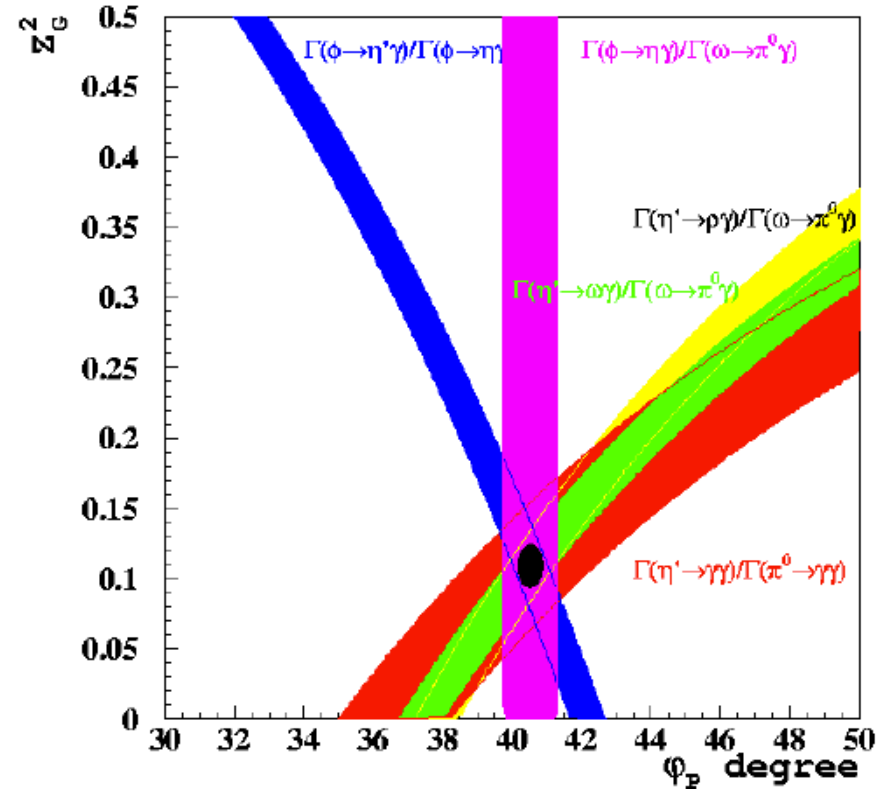
Processes	$(\delta\Gamma/\Gamma)_I$	$(\delta\Gamma/\Gamma)_{II}$	$(\delta\Gamma/\Gamma)_{III}$	$(\delta\Gamma/\Gamma)_{IV}$	$(\delta\Gamma/\Gamma)_V$	$(\delta\Gamma/\Gamma)_{VI}$
$\phi \rightarrow \eta'\gamma$	3.5%	3.5%	3.5%	1.7%	1.7%	1%
$\phi \rightarrow \eta\gamma$	2%	2%	2%	1%	1%	2%
$\eta' \rightarrow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

η' Gluonium VS η - η' Mixing

KLOE: JHEP07(2009)105



KLOE2: Run at $\sqrt{s} \geq 1.2$ GeV



Anomaly

- Box Anomaly: $\eta, \eta' \rightarrow \pi^+\pi^-\gamma$ 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
<i>VALUE</i>	<i>EVTS</i>	<i>DOCUMENT ID</i>	<i>TECN</i>	<i>COMMENT</i>	
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	$\psi(2S) \rightarrow J/\psi\eta$
0.209±0.004	18k	THALER	73	ASPK	
0.201±0.006	7250	GORMLEY	70	ASPK	

Theory HLS-Model:

$$\Gamma(\eta \rightarrow \pi^+\pi^-\gamma)_w = (56.3 \pm 1.7) \text{ eV}, \quad \Gamma(\eta \rightarrow \pi^+\pi^-\gamma)_{wo} = (100.9 \pm 2.8) \text{ eV}$$

KLOE/KLOE2:

$$\Gamma(\eta \rightarrow \pi^+\pi^-\gamma) = (54.7 \pm 3.1) \text{ eV} \text{ [PLB 718 (2013) 910–914]}$$

Anomaly

[KLOE/KLOE2PLB 718 (2013) 910–914]

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

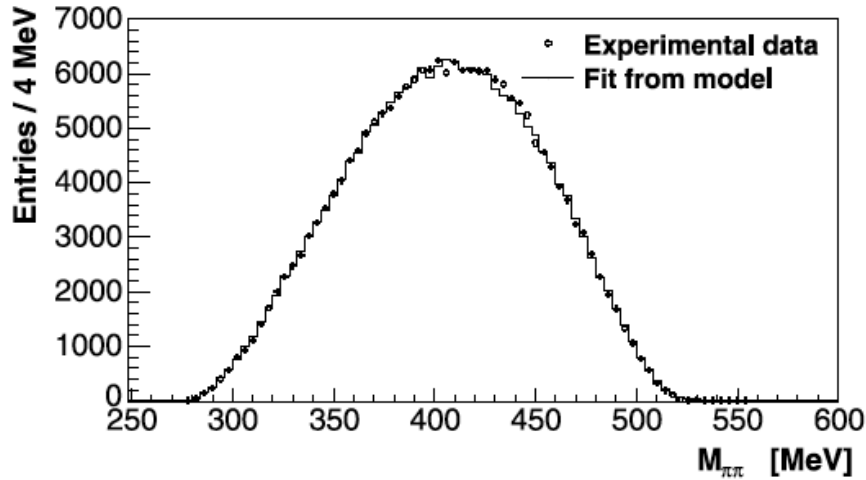


Fig. 4. Distribution of $M_{\pi\pi}$ after background subtraction (black markers). Histogram is the fit of Eq. (1), corrected for acceptance and experimental resolution.

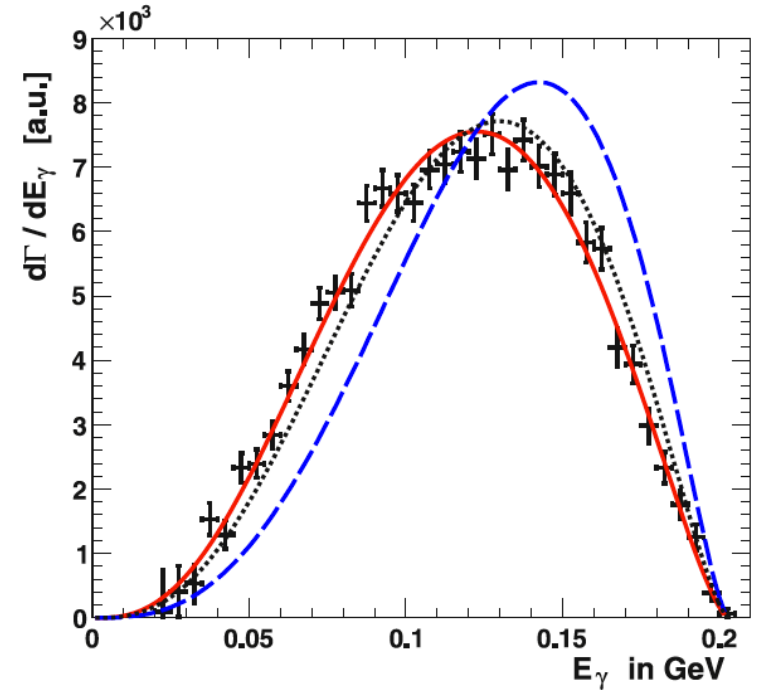
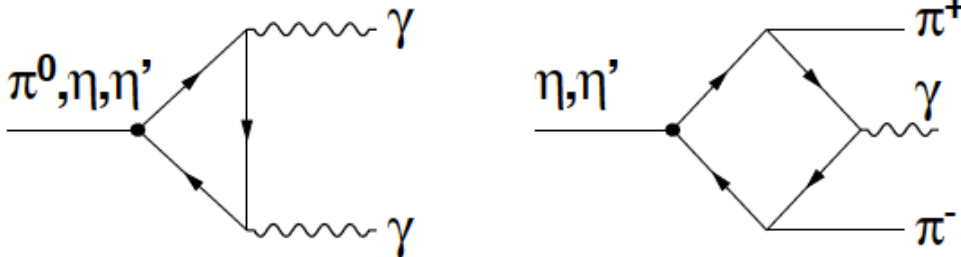


Fig. 6. The background subtracted and acceptance corrected angular distribution of the pions (top) and the photon energy distribution (bottom), with error bars indicating the statistical uncertainties. The angular distribution is compared with a relative p -wave of the pions (dashed curve). The shape 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 at 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