High statistics measurement of the $\omega\pi^0$ transition form factor

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Physics Advisory Committee Meeting

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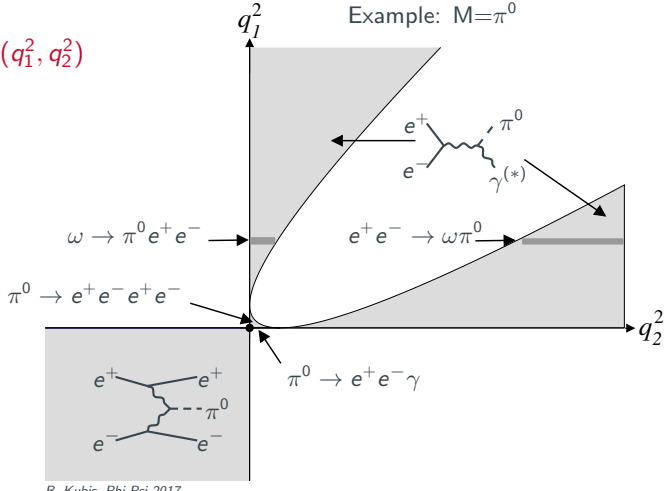
JGU Mainz

Introduction

Introduction - Meson Transition Form Factors

$$\mathcal{A}(M \leftrightarrow \gamma^{(*)}\gamma^{(*)}) = -ie^2 q_1^\mu \epsilon_1^\nu q_2^\alpha \epsilon_2^\beta \epsilon_{\mu\nu\alpha\beta} \mathcal{F}_M(q_1^2, q_2^2)$$

- Intrinsic probe of the electromagnetic hadron structure
- Important for in-medium studies of hadrons in heavy-ion collisions
- Precise knowledge needed for calculations of a_μ^{SM}



B. Kubis, Phi Psi 2017

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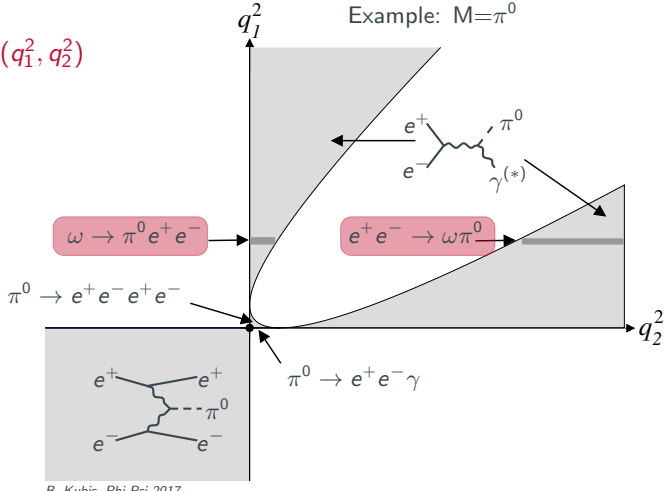

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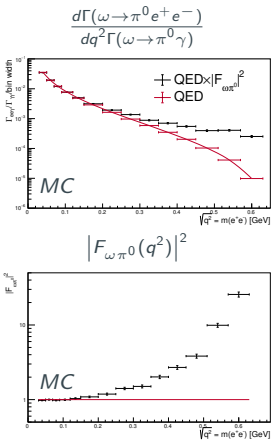
Introduction - Meson Transition Form Factors

Accessing the TFF — Momentum transfer spectrum of the decay rate

$$\frac{d\Gamma(\omega \to \pi^0 \ell^+ \ell^-)}{dq^2 \Gamma(\omega \to \pi^0 \gamma)} = [QED] \left| \frac{\mathcal{F}_{\omega\pi^0}(q^2)}{\mathcal{F}_{\omega\pi^0}(0)} \right|^2 = [QED] \left| F_{\omega\pi^0}(q^2) \right|^2$$

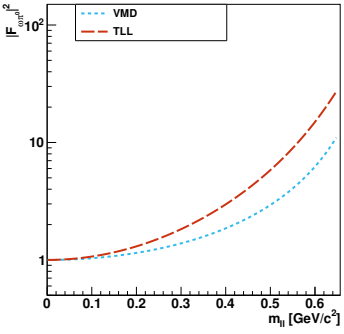


Compare results — VMD-inspired parametrisation

$$F_{\omega\pi^0}(q^2) = \frac{1}{1 - q^2\Lambda^{-2}} \qquad \Lambda^{-2} = \left. \frac{dF_{\omega\pi^0}(q^2)}{dq^2} \right|_{q^2=0}$$

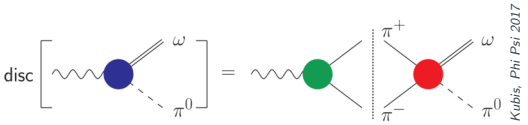
Introduction - Theory Models

- Vector Meson Dominance model [VMD]
- Chiral Lagrangian approach [TLL], $\mathcal{L}(V_{\mu\nu}, \Phi)$

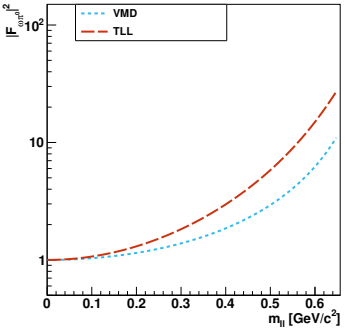


Introduction - Theory Models

- Vector Meson Dominance model [VMD]
- Chiral Lagrangian approach [TLL], $\mathcal{L}(V_{\mu\nu}, \Phi)$
- Dispersion analysis approaches



$\omega\pi^0$ TFF $\sim$ π vector form factor $\times$ $\omega \to 3\pi$ decay amplitude



Dealing with the behaviour of the amplitude in the inelastic region:

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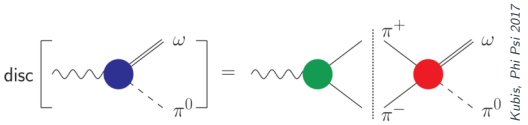

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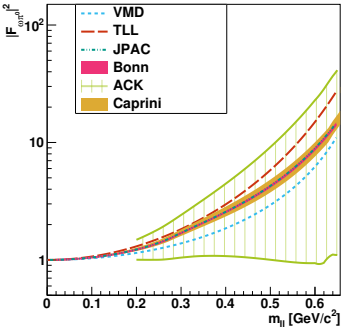


Dealing with the behaviour of the amplitude in the inelastic region:

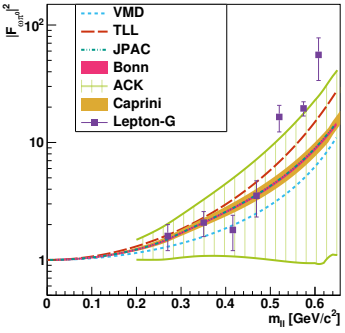
- Subtraction constants [Bonn]
- Parametrisation [JPAC]
- Integral condition using unitarity bounds [ACK]
- Constraints from $e^+e^- \to \omega\pi^0$ data [Caprini]

Introduction - Other Measurements

- Lepton-G

  $\pi^- p \to \omega n$ $\quad 60 \pm 9\ \omega \to \mu^+\mu^-\pi^0$ events

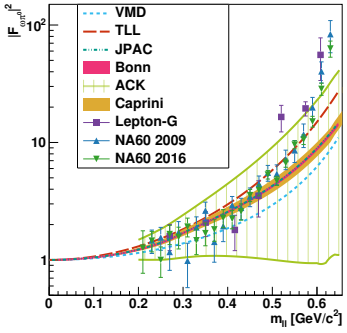
  exclusive measurement of final state

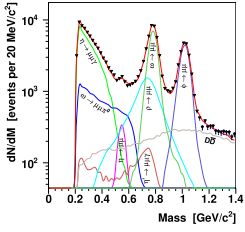


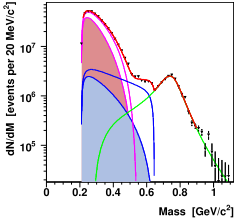
Introduction - Other Measurements

- Lepton-G
  $\pi^- p \to \omega n$ $\quad 60 \pm 9\ \omega \to \mu^+\mu^-\pi^0$ events
  exclusive measurement of final state

- NA60
  2009: In-In collisions, 3000 $\omega \to \mu^+\mu^-\pi^0$ events
  2016: p-A collisions, A = Be, Cu, In, W, Pb and U
  only measure $\mu^+\mu^-$







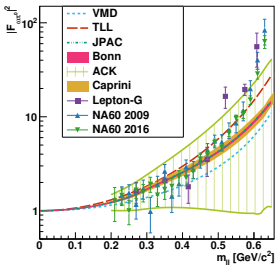
All MC cocktail subtracted except:
$\eta \to \mu^+\mu^-\gamma$, $\omega \to \mu^+\mu^-\pi^0$ and $\rho \to \mu^+\mu^-$

TFFs extracted from fits to subtracted corrected $\mu^+\mu^-$ spectrum

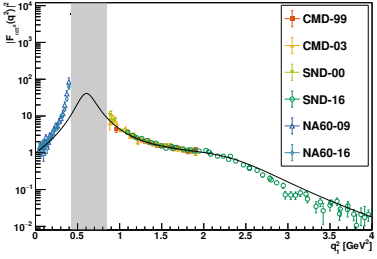
Introduction - Motivation

Significant theory efforts and high statistics $\mu^+\mu^-$ data $\longrightarrow$ Puzzling discrepancy at high $m_{\ell\ell}$

- Possible violation of unitarity bounds



- Asymmetric with $e^+e^- \to \omega\pi^0$



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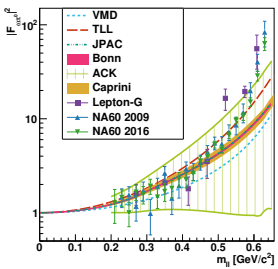
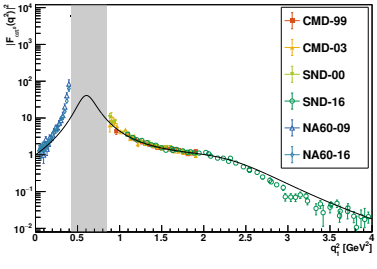
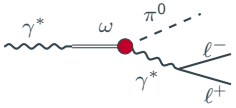




Complementary study with improved systematics needed

A2

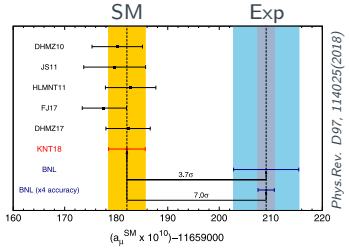
- Exclusive final state reconstruction
- Signal on smooth background



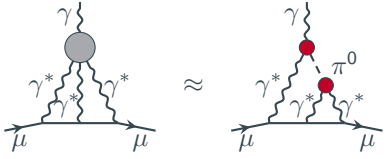
● : $\mathcal{F}\left(\pi^0 \leftrightarrow \gamma^{(*)}\gamma^{(*)}\right)$

Precision frontier of the SM — $a_\mu^{\text{SM}} - a_\mu^{\text{Exp}} \sim 3-4\ \sigma$

Increase precision of $a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{EW}} + a_\mu^{\text{HVP}} + a_\mu^{\text{HLbL}}$



Hadronic Light-by-Light scattering:



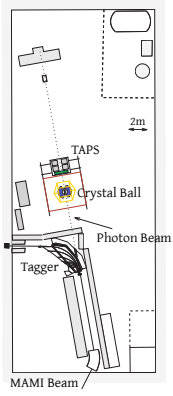
$+ \quad \cdots$

$\longrightarrow$ Data-driven theory approaches need experimental input on $\mathcal{F}_{\pi^0}(q_1^2, q_2^2)$

A2 measurement

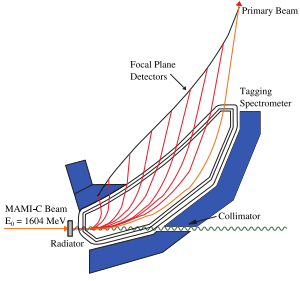
A2 measurement - Experimental setup

The tagger hall



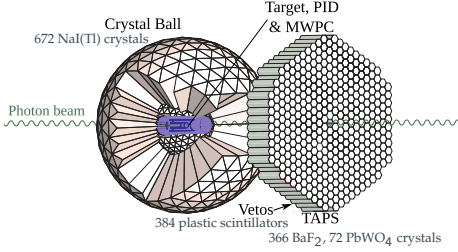
The Glasgow-Mainz photon tagger

Electrons + radiator → tagged bremsstrahlung photons



New tagger installed
2017-2018

The Crystal Ball + TAPS setup



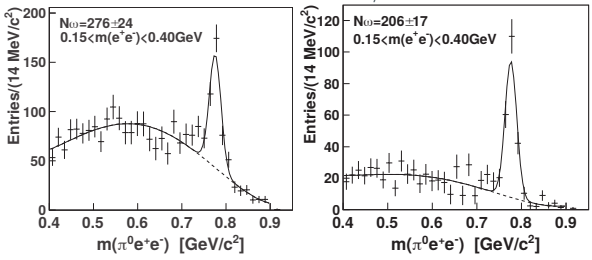
A2 measurement - Completed $\omega\pi^0$ TFF study

Beam times

2007: E_{MAMI} 1508 MeV, 5cm LH2 target

2009: E_{MAMI} 1557 MeV, 10cm LH2 target

Before and after cut on dE/dx in PID



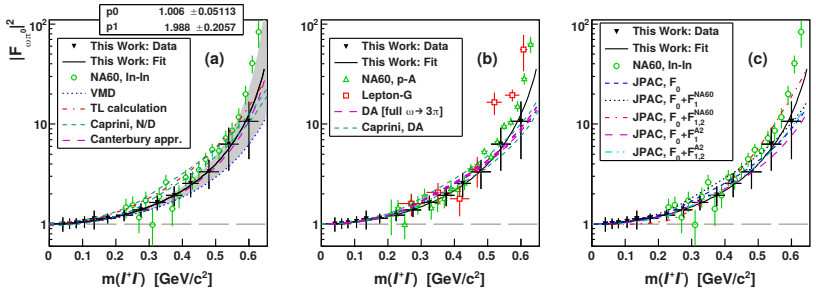
Event selection

- Exacly 5 cluster
- Contrained kinematic fit for candidate selection and reconstruction of event kinematics
- Identify e^+e^-, reduce conversion and reject non-resonant background with PID
- Cuts on cluster shape to reduce $\omega \to \pi^+\pi^-\pi^0$

Collected $\omega \to e^+e^-\pi^0$ statistics: $N_{ee\pi}^{2007} = 610$ and $N_{ee\pi}^{2009} = 460$

A2 measurement - Completed $\omega\pi^0$ TFF study

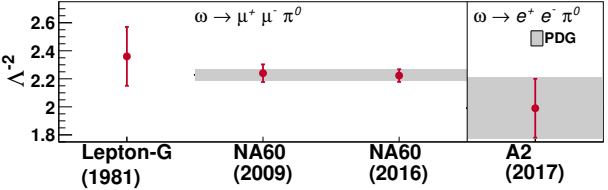
Results



datapoints with total uncertainties, $\sigma_{sys} \approx 0.2\sigma_{stat}$

$$F_{\omega\pi^0} = \frac{1}{1-q^2\Lambda^{-2}}$$

Lower but less precise

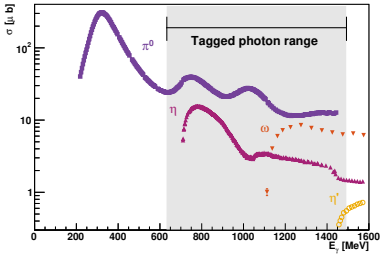


A2 measurement - Feasibility of high statistics $\omega\pi^0$ TFF from collected data

Beam time in 2019 dedicated to η/ω production:

E_{MAMI} 1604 MeV, 10cm LH2 target

- Increased tagged E_γ range
- A2 upgrades allow running at higher rates



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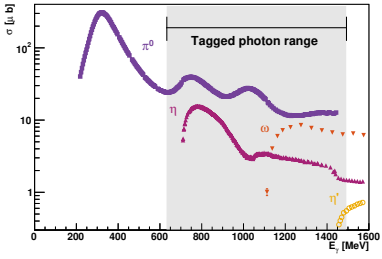


Estimation of achieved signal rate

Simple $\omega \to \gamma\pi^0$ analysis of 2007 (full) and 2019 (107h) data

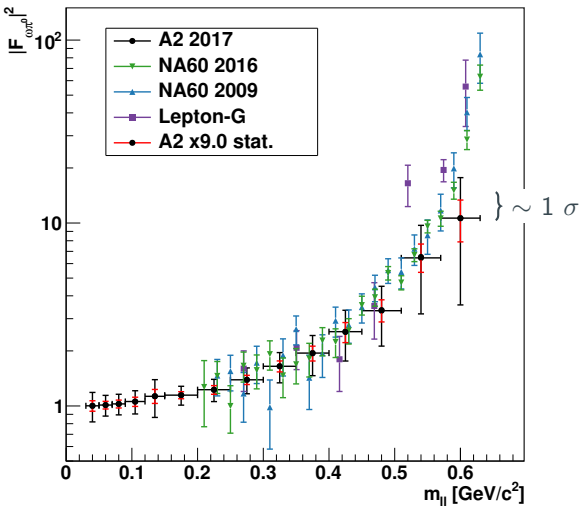
$$\omega \to e^+e^-\pi^0 \text{ rate} = N^{2007}_{ee\pi} \cdot \frac{N^{2019}_{\gamma\pi}}{N^{2007}_{\gamma\pi}} \cdot \frac{1}{107\text{h}} = \mathbf{8.7\ events/h}$$

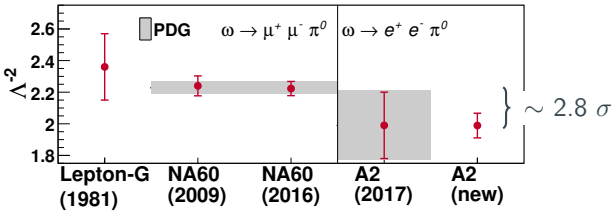
Including breaks (A2/MAMI repairs and tagging efficiency measurements): 5.2 events/h

Beam time estimate

Expected precision and beam time estimate

Suggested new statistics: **9** $\times$ 1070 signal events





$\longrightarrow$ 1100 h needed

	2019	Future
Good data	350 h	750 h
Empty target	35 h	77 h
Tagg.Eff.	11 h	24 h
		850 h

with breaks $\approx$ *7-8 weeks*

Further uses of the data set

Further uses of a high statistics data set

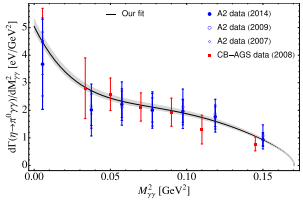
$$\gamma + p \to \eta/\omega + p$$

Increased statistics for previously performed studies using 2007+2009 data set

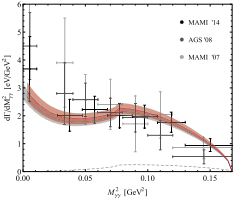
The rare $\eta \to \pi^0\gamma\gamma$ decay

- Probes ChPT to $\mathcal{O}(6)$
- Benchmark theory predictions

Linear σ model + VMD

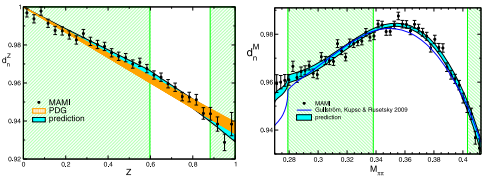


Dispersion formalism



Dalitz plot study of $\eta \to \pi^0\pi^0\pi^0$

- $\eta \to 3\pi$ access to $\frac{m_s^2 - m_{ud}^2}{m_d^2 - m_i^2}$
- Cusp at $\pi^+\pi^-$ threshold



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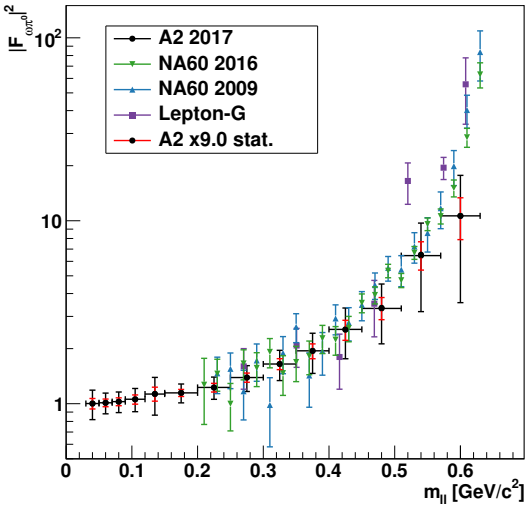

Proposal: A high statistics measurement of $\omega\pi^0$ TFF

- Puzzling theory - data discrepancy
- Benchmark theories needed for a_μ^{SM} precision

Settings

MAMI:	1604 MeV, unpol.
γ beam:	633 - 1492 MeV, Moeller rad., 3mm coll.
Trigger:	CB ESum $>$ 450 MeV
Equipment:	CB, TAPS, Veto, PID, MWPC, LH2 10cm

Beam time request

Data taking 850 hours ($\sim$ 7-8 weeks)

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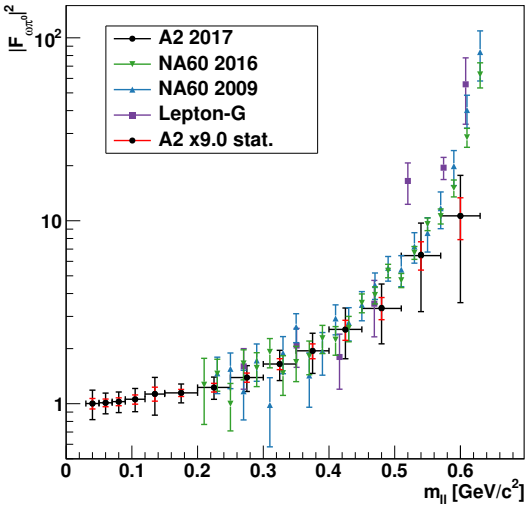

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Thank you for your attention

Backup slides

Beam time runconditions

	2007	2009	2019
E_{e^-}	1508 MeV	1557 MeV	1604 MeV
E_γ^{max}	1402 MeV	1448 MeV	1492 MeV
Radiator	10 μm Cu	10 μm Cu	10μm Fe/Co alloy
Collimator	4 mm	4 mm	3 mm
Target	5 cm LH2	10 cm LH2	10 cm LH2
Trigger	$E_{CB}^{sum} > 320$ MeV and M2+	$E_{CB}^{sum} > 340$ MeV and M3+	$E_{CB}^{sum} > 450$ MeV

A2 upgrades

- 2012-2013: DAQ upgrades $\sim$ double the speed of effective data taking
- 2017-2019: New Tagger $\sim$ from 1 to 2.5 MHz as individual counter rate

	2008	2018	Rate increase
Main difference	CBEsum 40 MeV lower, M2+ trigger used	Polarisation peak in $\Delta(1232)$ region	
$\pi^0 \to e^+e^-\gamma$ data	445 events/hour	2550 events/hour	5.5
Trigger rate	780 Hz	3500 Hz	4.5

$\longrightarrow$ Upgrades produced $> \times 4$ increase in data collection rate

Further uses of a high statistics data set

$$\gamma + p \to \eta/\omega + p$$

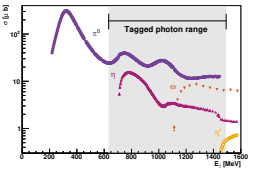
Increased statistics for previously performed studies using 2007+2009 data set

Decay studies

$\eta \to 3\pi^0$	$\pi\pi$ scattering, quark mass ratio	[PRC97 2018]
$\eta \to \pi^0\gamma\gamma$	Probe ChPT at $\mathcal{O}(6)$	[PRC90 2014]
$\eta \to 4\pi^0/3\gamma/\pi^0\gamma$	CP/C violation	

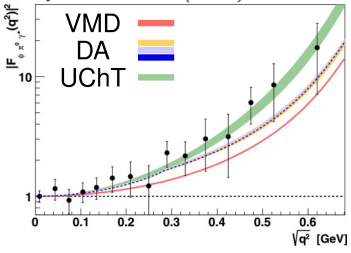
Cross section studies up to and above η' threshold with new Tagger

$\gamma p \to \pi^0\pi^0 p$	[PRC85 2012]	$\gamma p \to \eta p$	[PRL118 2017]
$\gamma p \to K^0\Sigma^+$	[PRC88 2013]	$\gamma p \to \omega p$	[PRC91 2015]
$\gamma p \to \eta\pi^0 p$	[PRC97 2017]		



$\phi \to \pi^0 e^+ e^-$ at KLOE

Phys.Lett. B757 (2016) 362-367



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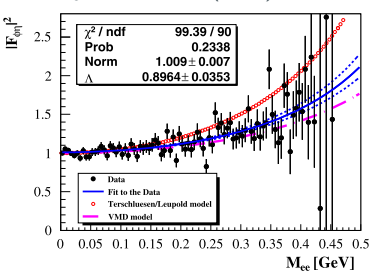
Phys.Lett. B742 (2015) 1-6



$J/\psi \to \eta e^+ e^-$ at BESIII

Phys.Rev. D99 (2019) 012006