

Precision tests of fundamental physics with light pseudoscalar mesons

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WORKSHOP TOPICS INCLUDE:

- Artificial intelligence and machine learning for hadron physics
- Electron Ion Collider and other future facilities and experiments
- Electroweak probes
- Extreme matter and neutron star collisions
- Hadrons in nuclei
- Hadron spectroscopy
- Hadron tomography
- Hadronization
- Heavy flavor and jet production
- Neutrino-hadron interactions
- New physics and discrete symmetry violation in hadron physics
- Nonequilibrium dynamics
- Nucleon and nuclear spin physics
- Origin of hadron mass
- Physics of the quark-gluon plasma
- Quantum information for hadron physics
- Small systems and collectivity
- Transverse and longitudinal structure of hadrons
- Ultraperipheral Collisions

10th WORKSHOP OF THE APS TOPICAL GROUP ON HADRONIC PHYSICS

The GHP workshop is a great opportunity for nuclear and particle physicists to share their research and common interests in hadronic physics. We welcome your attendance and participation. Please encourage your students and postdocs to take part.



The workshop immediately precedes the APS April Meeting 2023 and is at the same venue.

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GHP 2023
WORKSHOP

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- ▶ $\eta \rightarrow \pi^0 \gamma \gamma$ decays: testing χPT and VMD models
- ▶ $\eta \rightarrow \pi^0 \gamma \gamma$ decays: leptophobic B -boson contribution
- ▶ Summary

Why is it interesting to study η/η' physics?

- Quantum numbers $I^G J^{PC} = 0^+ 0^{-+}$:
 - Eigenstates of the C, P, CP and G operators
 - Flavor conserving decays \Rightarrow laboratory for symmetry tests
 - All their strong and EM decays are forbidden at lowest order
 - The η is a pseudo-Goldstone boson
 - The η' is largely influenced by the $U(1)$ anomaly
- Large amount of data have been collected:
 - A2@MAMI, BESIII, CLAS, CrystalBall, GlueX, KLOE(-II), WASA
- More to come:
 - JEF (talk by B. Briscoe), REDTOP (talk by C. Gatto)

Why is it interesting to study η/η' physics?

- Unique opportunity to:
 - Test chiral dynamics at low energy
 - Extract fundamental parameters of the Standard Model (light quark masses, η - η' mixing)
 - Study of fundamental symmetries: P & CP and P & CP violation
 - Looking for BSM physics \Rightarrow Dark sector
- Theoretical methods:
 - ChPT and its extensions (large- N_c)
 - Vector-meson dominance
 - Dispersion theory

Selected η/η' decays

- **High priority** $\eta^{(\prime)}$ decays for experiment and theory
(L. Gan, B. Kubis, E. Passemar and S. Tulin, 2007.00664)

Decay channel	Standard Model	Discrete symmetries	BSM particles
$\eta^{(\prime)} \rightarrow \pi^+ \pi^- \pi^0$	light quark masses	C/CP violation	scalar bosons
$\eta^{(\prime)} \rightarrow \gamma\gamma$	η - η' mixing, width	—	—
$\eta^{(\prime)} \rightarrow \ell^+ \ell^- \gamma$	$(g-2)_\mu$	—	Z' , dark photon
$\eta^{(\prime)} \rightarrow \pi^0 \gamma\gamma$ and $\eta' \rightarrow \eta\gamma\gamma$	higher-order χ PT, scalar dynamics	—	$U(1)_B$ boson, scalar boson
$\eta^{(\prime)} \rightarrow \mu^+ \mu^-$	$(g-2)_\mu$, precision tests	CP violation	—
$\eta^{(\prime)} \rightarrow \pi^0 \ell^+ \ell^-$	—	C violation	scalar bosons
$\eta^{(\prime)} \rightarrow \pi^+ \pi^- \ell^+ \ell^-$	$(g-2)_\mu$	—	ALP, dark photon
$\eta^{(\prime)} \rightarrow \pi^0 \pi^0 \ell^+ \ell^-$	—	C violation	ALP

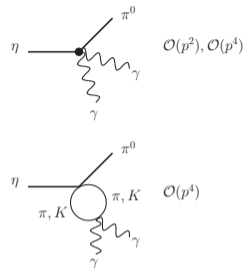
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$\eta \rightarrow \pi^0 \gamma \gamma$ decays: Theoretical motivation

- SM motivation:

Reference	$\Gamma(\eta \rightarrow \pi^0 \gamma \gamma)$ [eV]
$\mathcal{O}(p^2), \mathcal{O}(p^4)$ tree-level χ PT	0
$\pi + K$ loops at $\mathcal{O}(p^4)$	1.87×10^{-3}
Experimental value (pdg)	0.34(3)



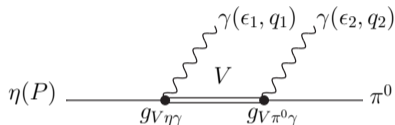
- 1st sizable contribution comes at $\mathcal{O}(p^6)$, but LEC's are not well known
- To test **ChPT** and a wide range of chiral models, *e. g.* VMD and $L\sigma M$



- BSM motivation: search for a B boson via $\eta \rightarrow B \gamma \rightarrow \pi^0 \gamma \gamma$

Vector meson exchange contributions

- Six diagrams corresponding to the exchange of $V = \rho^0, \omega, \phi$



$$\mathcal{A}_{\eta \rightarrow \pi^0 \gamma \gamma}^{\text{VMD}} = \sum_{V=\rho^0, \omega, \phi} g_{V\eta\gamma} g_{V\pi^0\gamma} \left[\frac{(P \cdot q_2 - m_\eta^2)\{a\} - \{b\}}{D_V(t)} + \left\{ \begin{array}{l} q_2 \leftrightarrow q_1 \\ t \leftrightarrow u \end{array} \right\} \right],$$

- Mandelstam variables and Lorentz structures given by:

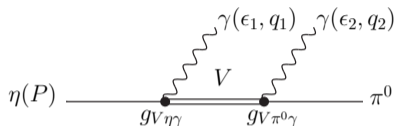
$$t, u = (P - q_{2,1})^2 = m_\eta^2 - 2P \cdot q_{2,1},$$

$$\{a\} = (\epsilon_1 \cdot \epsilon_2)(q_1 \cdot q_2) - (\epsilon_1 \cdot q_2)(\epsilon_2 \cdot q_1),$$

$$\begin{aligned} \{b\} &= (\epsilon_1 \cdot q_2)(\epsilon_2 \cdot P)(P \cdot q_1) + (\epsilon_2 \cdot q_1)(\epsilon_1 \cdot P)(P \cdot q_2) \\ &\quad - (\epsilon_1 \cdot \epsilon_2)(P \cdot q_1)(P \cdot q_2) - (\epsilon_1 \cdot P)(\epsilon_2 \cdot P)(q_1 \cdot q_2) \end{aligned}$$

$\eta \rightarrow \pi^0 \gamma \gamma$ decays: VMD calculation

- Six **diagrams** corresponding to the exchange of $V = \rho^0, \omega, \phi$



$$\mathcal{A}_{\eta \rightarrow \pi^0 \gamma \gamma}^{\text{VMD}} = \sum_{V=\rho^0, \omega, \phi} g_{V\eta\gamma} g_{V\pi^0\gamma} \left[\frac{(P \cdot q_2 - m_\eta^2)\{a\} - \{b\}}{D_V(t)} + \left\{ \begin{array}{l} q_2 \leftrightarrow q_1 \\ t \leftrightarrow u \end{array} \right\} \right],$$

- $g_{VP\gamma}$ **couplings**:

— Model-based:

$$\mathcal{L}_{VVP} = \frac{G}{\sqrt{2}} \epsilon^{\mu\nu\alpha\beta} \text{tr} [\partial_\mu V_\nu \partial_\alpha V_\beta P], \quad \mathcal{L}_{V\gamma} = -2egf_\pi^2 A^\mu \text{tr} [QV_\mu],$$

— Empirical: measured $\Gamma_{V(P) \rightarrow P(V)\gamma}^{\text{exp}}$ widths

- The decays $\eta' \rightarrow \{\pi^0, \eta\} \gamma \gamma$ are formally identical: $g_{V\eta\gamma} g_{V\pi^0\gamma} \rightarrow g_{V\eta'\gamma} g_{V\{\pi^0, \eta\}\gamma}$

Input for the $g_{VP\gamma}$ couplings

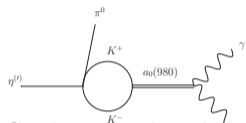
- $g_{VP\gamma}$ couplings fixed from the measured widths ($P = \pi^0, \eta, \eta'$)

$$\Gamma_{V \rightarrow P\gamma}^{\text{exp}} = \frac{1}{3} \frac{g_{VP\gamma}^2}{32\pi} \left(\frac{m_V^2 - m_P^2}{m_V} \right)^3, \quad \Gamma_{P \rightarrow V\gamma}^{\text{exp}} = \frac{g_{VP\gamma}^2}{32\pi} \left(\frac{m_P^2 - m_V^2}{m_P} \right)^3,$$

Decay	Branching ratio (pdg)	$ g_{VP\gamma} \text{ GeV}^{-1}$
$\rho^0 \rightarrow \pi^0\gamma$	$(4.7 \pm 0.6) \times 10^{-4}$	0.22(1)
$\rho^0 \rightarrow \eta\gamma$	$(3.00 \pm 0.21) \times 10^{-4}$	0.48(2)
$\eta' \rightarrow \rho^0\gamma$	$(28.9 \pm 0.5)\%$	0.40(1)
$\omega \rightarrow \pi^0\gamma$	$(8.40 \pm 0.22)\%$	0.70(1)
$\omega \rightarrow \eta\gamma$	$(4.5 \pm 0.4) \times 10^{-4}$	0.135(6)
$\eta' \rightarrow \omega\gamma$	$(2.62 \pm 0.13)\%$	0.127(4)
$\phi \rightarrow \pi^0\gamma$	$(1.30 \pm 0.05) \times 10^{-3}$	0.041(1)
$\phi \rightarrow \eta\gamma$	$(1.303 \pm 0.025)\%$	0.2093(20)
$\phi \rightarrow \eta'\gamma$	$(6.22 \pm 0.21) \times 10^{-5}$	0.216(4)

$L\sigma M$ for the scalar resonance contributions

- χ PT loops complemented by the exchange of scalar resonances, $a_0(980), \kappa, \sigma, f_0(980)$, e.g.:



$$\mathcal{A}_{\eta^{(\prime)} \rightarrow \pi^0 \gamma \gamma}^{\text{L}\sigma\text{M}} = \frac{2\alpha}{\pi} \frac{1}{m_{K^+}^2} L(s_K) \{a\} \times \mathcal{A}_{K^+ K^- \rightarrow \pi^0 \eta^{(\prime)}}^{\text{L}\sigma\text{M}},$$

- Scalar amplitudes:?

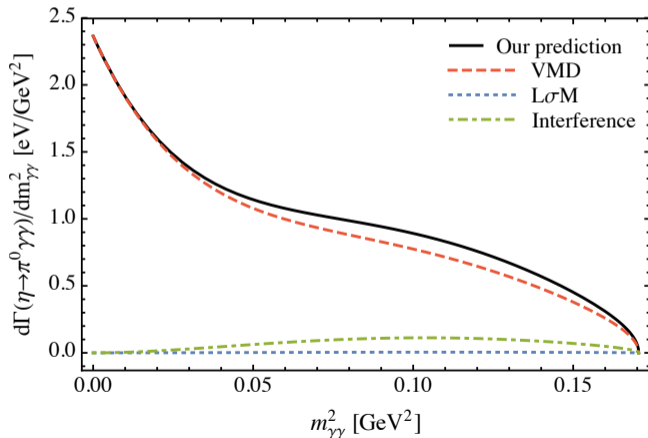
$$\mathcal{A}_{K^+ K^- \rightarrow \pi^0 \eta^{(\prime)}}^{\text{L}\sigma\text{M}} = \frac{1}{2f_\pi f_K} \left\{ (s - m_{\eta^{(\prime)}}^2) \frac{m_K^2 - m_{a_0}^2}{D_{a_0}(s)} \cos \varphi_P + \frac{1}{6} \left[(5m_{\eta^{(\prime)}}^2 + m_\pi^2 - 3s) \cos \varphi_P - \sqrt{2}(m_{\eta^{(\prime)}}^2 + 4m_K^2 + m_\pi^2 - 3s) \sin \varphi_P \right] \right\},$$

- Complete one-loop propagator for the scalar resonances:

$$D_R(s) = s - m_R^2 + \text{Re}\Pi(s) - \text{Re}\Pi(m_R^2) + i\text{Im}\Pi(s),$$

$\eta \rightarrow \pi^0 \gamma \gamma$ predictions

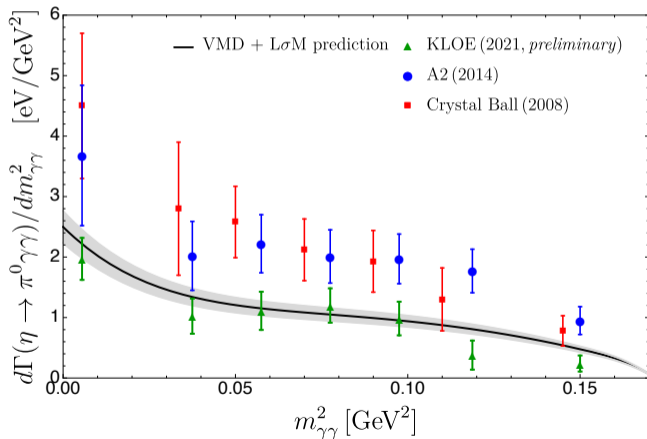
- Our theoretical prediction $BR = 1.35(8) \times 10^{-4}$ ([Phys.Rev.D 102, 034026 \(2020\)](#))
 - VMD dominates:
 - ρ : 27% of the signal
 - ω : 21% of the signal
 - ϕ : 0% of the signal
 - interference between ρ - ω - ϕ : 52%
 - interference between scalar and vector mesons: 7%



$\eta \rightarrow \pi^0 \gamma \gamma$ predictions

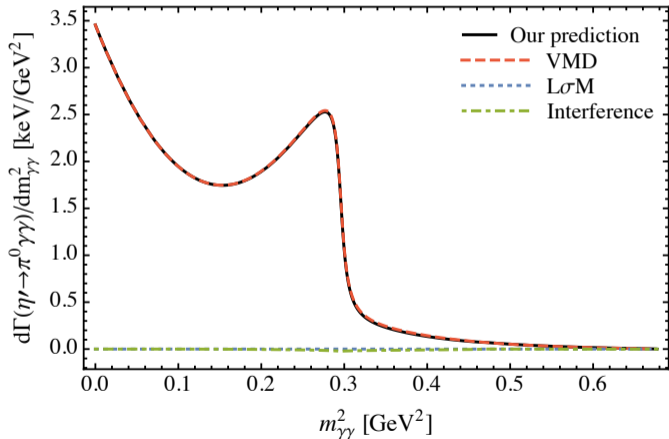
- Comparison with experimental data ([Phys.Rev.D 102, 034026 \(2020\)](#))

- Shape of the A2 and Crystal Ball spectra is captured well (normalization offset)
- Good agreement with (preliminary) KLOE data ([del Rio CD'21](#))
- KLOE: Last checks on systematics are ongoing ([Berlowski DNP'22](#))



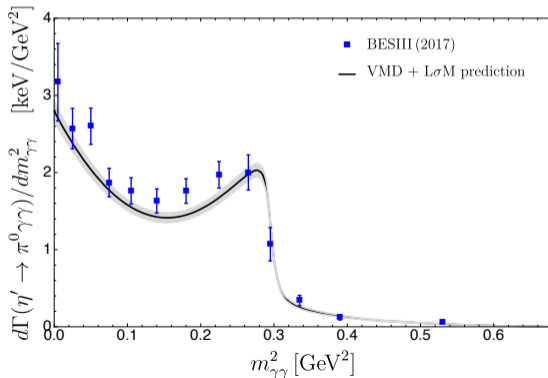
$\eta' \rightarrow \pi^0 \gamma \gamma$ predictions

- Our theoretical prediction $BR = 2.91(21) \times 10^{-3}$ ([Phys.Rev.D 102, 034026 \(2020\)](#))
 - VMD completely dominates:
 - ω : 78% of the signal
 - ρ : 5% of the signal
 - ϕ : 0% of the signal
 - interference: 17%



$\eta' \rightarrow \pi^0 \gamma \gamma$ predictions

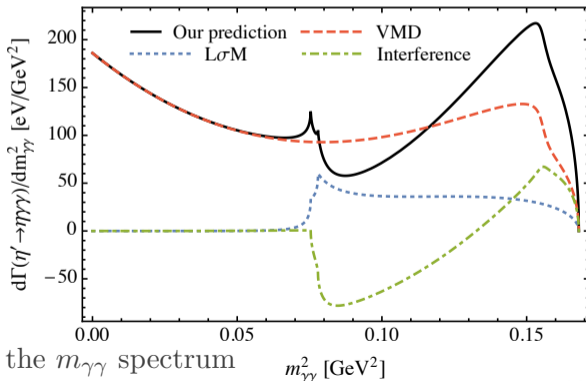
- Our theoretical prediction $BR = 2.91(21) \times 10^{-3}$ ([Phys.Rev.D 102, 034026 \(2020\)](#))
- First time $m_{\gamma\gamma}$ invariant mass distribution by BESIII;
 $BR = 3.20(7)(23) \times 10^{-3}$ ([Ablikim *et. al.* Phys.Rev.D 96, 012005 \(2017\)](#))



$\eta' \rightarrow \eta\gamma\gamma$ predictions

- 1st BR measurement by BESIII, $BR = 8.25(3.41)(0.72) \times 10^{-5}$ or $BR < 1.33 \times 10^{-4}$ at 90% C.L. (Ablikim *et. al.* Phys.Rev.D 100, 052015 (2019))
- Our theoretical predictions $BR = 1.17(8) \times 10^{-4}$
(R. Escribano, S. G-S, R. Jora, E. Royo, Phys.Rev.D 102, 034026 (2020))

- VMD predominates (91% of the signal)
- Substantial scalar meson effects (16%)
- Interference between scalar and vector mesons (7%)



- We look forward to the release of the $m_{\gamma\gamma}$ spectrum

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Leptophobic B boson model

- New boson arising from a new $U(1)_B$ gauge symmetry

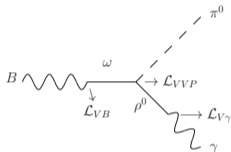
$$\mathcal{L}_{\text{int}} = \left(\frac{1}{3} g_B + \varepsilon Q_q e \right) \bar{q} \gamma^\mu q B_\mu - \varepsilon e \bar{\ell} \gamma^\mu \ell B_\mu,$$

- Couples (predominantly) to quarks
- g_B new gauge (universal?) coupling, $\alpha_B = g_B^2/4\pi$
- Preserves QCD symmetries (C, P, T)
- B is a singlet under isospin:
 $I^G(J^{PC}) = 0^-(1^{--}) \Rightarrow B$ is ω **meson** like
- $\varepsilon = eg_B/(4\pi)^2$: (subleading) γ -like coupling to fermions

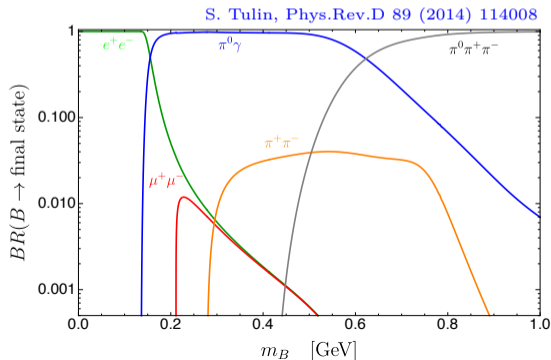
- Searches depend on the mass m_B and decay channels
- Searches on meson decays are gaining attention
 - $\phi \rightarrow \eta B \rightarrow \eta \pi^0 \gamma$ (KLOE-II), $\eta \rightarrow \pi^0 \gamma \gamma$ (JEF), $\eta \rightarrow \pi^+ \pi^- \gamma$ (Belle-II)

Calculation of hadronic processes

- Following the conventional **VMD picture**, $\mathcal{L}_{V\gamma} \rightarrow \mathcal{L}_{VB}$
 - $A^\mu \rightarrow B^\mu$, $e \rightarrow g_B$ and $Q = 1/3$, $\mathcal{L}_{VB} = -2\frac{1}{3}g_B g f_\pi^2 B^\mu \text{tr}[V^\mu]$,



$$\Gamma_{B \rightarrow \pi^0 \gamma} = \frac{\alpha_B \alpha_{em} m_B^3}{96 \pi^3 f_\pi^2} \left(1 - \frac{m_\pi^2}{m_B^2}\right)^3 |F_\omega(m_B^2)|^2,$$



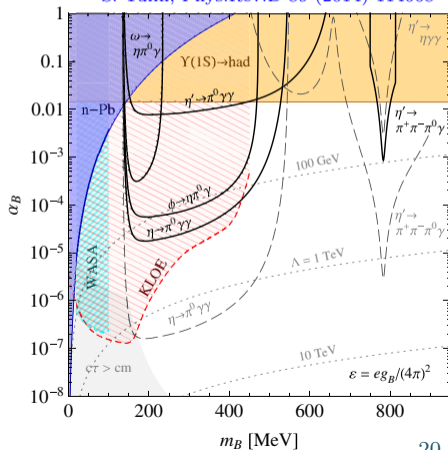
Previous limits on α_B and m_B

- Assuming the **Narrow-Width Approximation (NWA)**

$$BR(\eta \rightarrow \pi^0 \gamma \gamma) = BR(\eta \rightarrow B \gamma) \times BR(B \rightarrow \pi^0 \gamma),$$

S. Tulin, Phys.Rev.D 89 (2014) 114008

- QCD contribution **off**
- $BR(\eta \rightarrow \pi^0 \gamma \gamma) < BR_{\text{exp}}$ at 2σ
 - $BR(\eta \rightarrow \pi^0 \gamma \gamma)_{\text{exp}} = 2.21(53) \times 10^{-4}$
 - $BR(\eta' \rightarrow \pi^0 \gamma \gamma)_{\text{exp}} < 8 \times 10^{-4}$ (90% C.L.)
 - $BR(\eta' \rightarrow \eta \gamma \gamma)_{\text{exp}}$ no data



Present limits on α_B and m_B

- Assuming the **Narrow-Width** Approximation (NWA)

$$BR(\eta \rightarrow \pi^0 \gamma \gamma) = BR(\eta \rightarrow B \gamma) \times BR(B \rightarrow \pi^0 \gamma),$$

- QCD contribution **off**
- $BR(\eta \rightarrow \pi^0 \gamma \gamma) < BR_{\text{exp}}$ at 2σ

— $BR(\eta \rightarrow \pi^0 \gamma \gamma)_{\text{exp}}^{\text{pdg}} = 2.56(22) \times 10^{-4}$

— $BR(\eta \rightarrow \pi^0 \gamma \gamma)_{\text{exp}}^{\text{KLOE}} = 1.23(14) \times 10^{-4}$

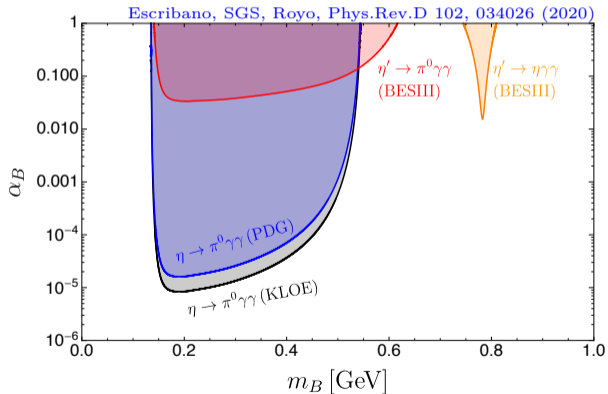
B. Cao [KLOE], PoS EPS-HEP2021 (2022) 409

— $BR(\eta' \rightarrow \pi^0 \gamma \gamma)_{\text{exp}} = 3.20(7)(23) \times 10^{-3}$

M. Ablikim *et.al* [BESIII], Phys.Rev. D 96 (2017) 012005

— $BR(\eta' \rightarrow \eta \gamma \gamma)_{\text{exp}} = 8.25(3.41)(72) \times 10^{-5}$

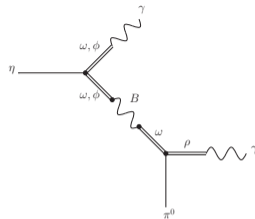
M. Ablikim *et.al* [BESIII], Phys.Rev. D 100 (2019) 052015



$\eta \rightarrow \pi^0 \gamma \gamma$ decays: B boson calculation

- Two diagrams corresponding to the exchange of a B boson

$$\mathcal{A}_{\eta \rightarrow \pi^0 \gamma \gamma}^{B \text{ boson}} = g_{B\eta\gamma}(t) g_{B\pi^0\gamma}(t) \left[\frac{(P \cdot q_2 - m_\eta^2)\{a\} - \{b\}}{m_B^2 - t - i\sqrt{t}\Gamma_B(t)} + \left\{ \begin{array}{l} q_2 \leftrightarrow q_1 \\ t \leftrightarrow u \end{array} \right\} \right],$$

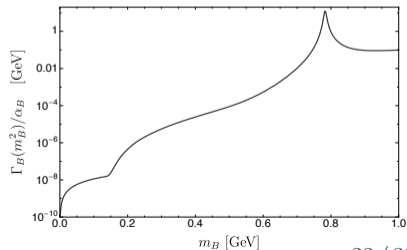


- $g_{BP\gamma}$ couplings:

$$g_{B\pi^0\gamma}(t) = \frac{\sqrt{2}eg_B}{4\pi^2 f_\pi} F_\omega(t), \quad g_{B\eta\gamma}(t) = \frac{eg_B}{12\pi^2 f_\pi} \frac{1}{\sqrt{3}} \left[(c_\theta - \sqrt{2}s_\theta)F_\omega(t) + (2c_\theta + \sqrt{2}s_\theta)F_\phi(t) \right],$$

- Energy-dependent width

$$\begin{aligned} \Gamma_B(q^2) &= \frac{\gamma_{B \rightarrow \ell^+ \ell^-}(q^2)}{\gamma_{B \rightarrow \ell^+ \ell^-}(m_B^2)} \Gamma_{B \rightarrow \ell^+ \ell^-} \theta(q^2 - 4m_\ell^2) \\ &+ \frac{\gamma_{B \rightarrow \pi^0 \gamma}(q^2)}{\gamma_{B \rightarrow \pi^0 \gamma}(m_B^2)} \Gamma_{B \rightarrow \pi^0 \gamma} \theta(q^2 - m_{\pi^0}^2) \\ &+ \frac{\gamma_{B \rightarrow \pi\pi}(q^2)}{\gamma_{B \rightarrow \pi\pi}(m_B^2)} \Gamma_{B \rightarrow \pi\pi} \theta(q^2 - 4m_\pi^2) \\ &+ \frac{\gamma_{B \rightarrow 3\pi}(q^2)}{\gamma_{B \rightarrow 3\pi}(m_B^2)} \Gamma_{B \rightarrow 3\pi} \theta(q^2 - 9m_\pi^2) \end{aligned}$$



New limits on α_B and m_B

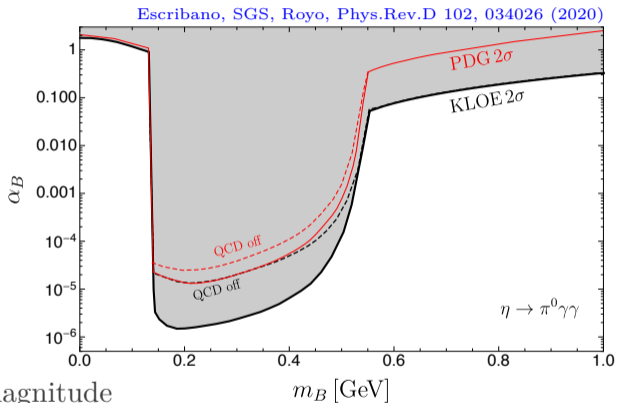
- Not assuming the NWA
- QCD contribution on
- $BR(\eta \rightarrow \pi^0 \gamma \gamma) < BR_{\text{exp}}$ at 2σ

— $BR(\eta \rightarrow \pi^0 \gamma \gamma)_{\text{exp}}^{\text{pdg}} = 2.56(22) \times 10^{-4}$

— $BR(\eta \rightarrow \pi^0 \gamma \gamma)_{\text{exp}}^{\text{KLOE}} = 1.23(14) \times 10^{-4}$

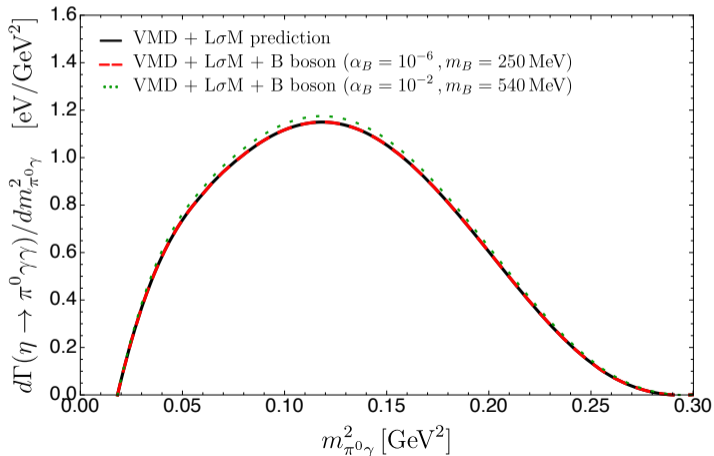
B. Cao [KLOE], PoS EPS-HEP2021 (2022) 409

- Limits strengthened by one order of magnitude



$\pi^0\gamma$ mass distribution

- These constraints would make a B boson signature suppressed
- $\pi^0\gamma$ distribution will be very welcome (JEF?)



New limits on α_B and m_B

- Not assuming the NWA
- QCD contribution on
- $BR < BR_{\text{exp}}$ at 2σ

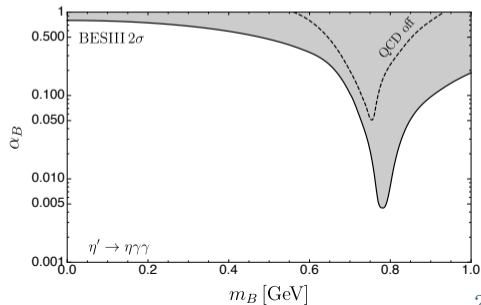
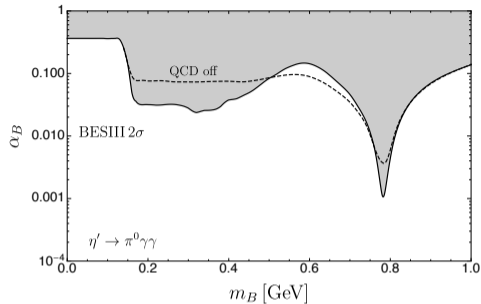
— $BR(\eta' \rightarrow \pi^0 \gamma \gamma)_{\text{exp}} = 3.20(7)(23) \times 10^{-3}$

M. Ablikim *et.al* [BESIII], Phys.Rev. D 96 (2017) 012005

— $BR(\eta' \rightarrow \eta \gamma \gamma)_{\text{exp}} = 8.25(3.41)(72) \times 10^{-5}$

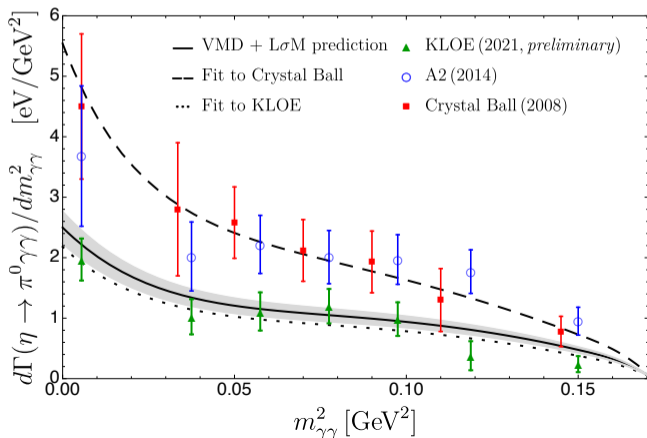
M. Ablikim *et.al* [BESIII], Phys.Rev. D 100 (2019) 052015

- Sharp dip when $m_B \sim m_\omega$
- Bounds 4 orders of magnitude weaker than $\eta \rightarrow \pi^0 \gamma \gamma$



Fits to the $\eta \rightarrow \pi^0 \gamma \gamma$ decays

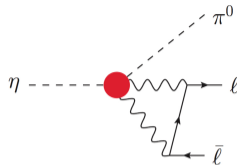
- Crystal Ball: $\alpha_B = 0.40_{-0.08}^{+0.07}$, $m_B = 583_{-20}^{+32}$ MeV, $\chi_{\text{dof}}^2 = 0.4/5 = 0.1$
- KLOE: $\alpha_B = 0.049_{-27}^{+40}$, $m_B = 135_{-135}^{+1}$ MeV, $\chi_{\text{dof}}^2 = 4.5/5 = 0.9$
- signatures outside $m_{\pi^0} \lesssim m_B \lesssim m_\eta$ may be visible



$\eta^{(\prime)} \rightarrow \{\pi^0, \eta\} \ell^+ \ell^-$ decays ($\ell = e, \mu$)

- In the SM:

- $\eta \rightarrow \pi^0 \gamma^* \rightarrow \pi^0 \ell^+ \ell^-$ forbidden by C and CP
- $\eta \rightarrow \pi^0 \ell^+ \ell^-$ proceed via C -conserving two-photon intermediate state



Decay channel	BR_{th} (Escribano&Royo 2007.12467)	BR_{exp} (pdg)
$\eta \rightarrow \pi^0 e^+ e^-$	$2.1(1)(2) \times 10^{-9}$	$< 7.5 \times 10^{-6}$ (CL=90%)
$\eta \rightarrow \pi^0 \mu^+ \mu^-$	$1.2(1)(1) \times 10^{-9}$	$< 5 \times 10^{-6}$ (CL=90%)
$\eta' \rightarrow \pi^0 e^+ e^-$	$4.6(3)(7) \times 10^{-9}$	$< 1.4 \times 10^{-3}$ (CL=90%)
$\eta' \rightarrow \pi^0 \mu^+ \mu^-$	$1.8(1)(2) \times 10^{-9}$	$< 6.0 \times 10^{-5}$ (CL=90%)
$\eta' \rightarrow \eta e^+ e^-$	$3.9(3)(4) \times 10^{-10}$	$< 2.4 \times 10^{-3}$ (CL=90%)
$\eta' \rightarrow \eta \mu^+ \mu^-$	$1.6(1)(2) \times 10^{-10}$	$< 1.5 \times 10^{-5}$ (CL=90%)

- Background for BSM searches, *e.g.* C -violating virtual photon exchange or new scalar mediators
- REDTOP can improve the experimental state

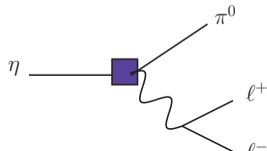


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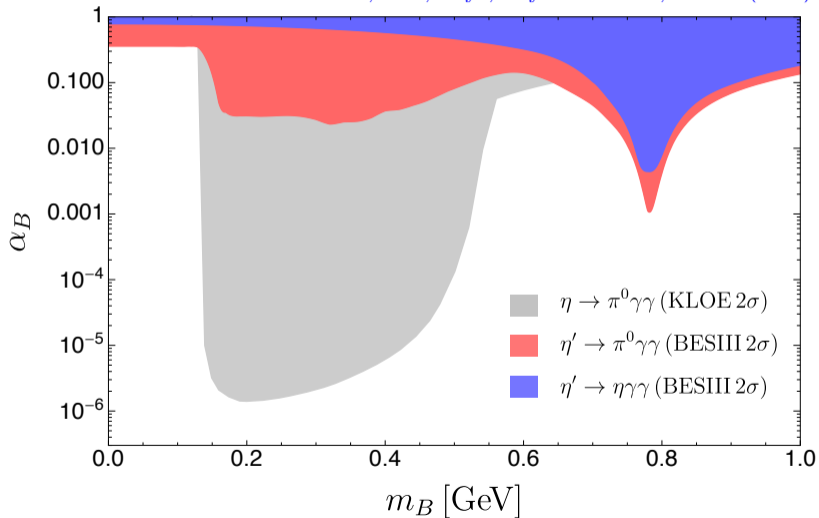
- ▶ Introduction
- ▶ $\eta \rightarrow \pi^0 \gamma \gamma$ decays: testing χPT and VMD models
- ▶ $\eta \rightarrow \pi^0 \gamma \gamma$ decays: leptophobic B -boson contribution
- ▶ Summary

Summary

- Within the VMD and $L\sigma M$ frameworks **we have described**
 - $\eta \rightarrow \pi^0 \gamma \gamma$: the situation is **not conclusive**
 $BR = 1.35(8) \times 10^{-4} \left\{ \begin{array}{ll} \sim 1/2 \text{ of } BR = 2.54(27) \times 10^{-4} & \text{(A2, 2014)} \\ \sim 1.6\sigma \text{ from } BR = 2.21(24)(47) \times 10^{-4} & \text{(CB, 2008)} \\ \text{agrees with } BR = 1.23(14) \times 10^{-4} & \text{(KLOE prel., 2022)} \end{array} \right.$
 - $\eta' \rightarrow \pi^0 \gamma \gamma$: **in fair agreement** with BESIII data
 - $\eta' \rightarrow \eta \gamma \gamma$: **in line** with BESIII data
- **Sensitivity** to B boson has been analyzed
- **Constraints** on α_B, m_B have been strengthened by one order of magnitude from $\eta \rightarrow \pi^0 \gamma \gamma$
- The contribution of **new experiments** (JEF, REDTOP), will be very welcome!

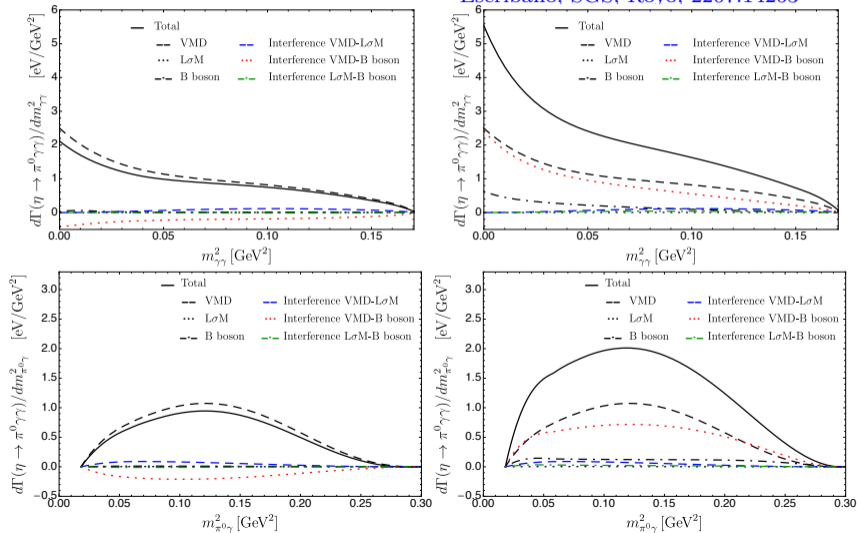
Summary

Escribano, SGS, Royo, Phys.Rev.D 102, 034026 (2020)



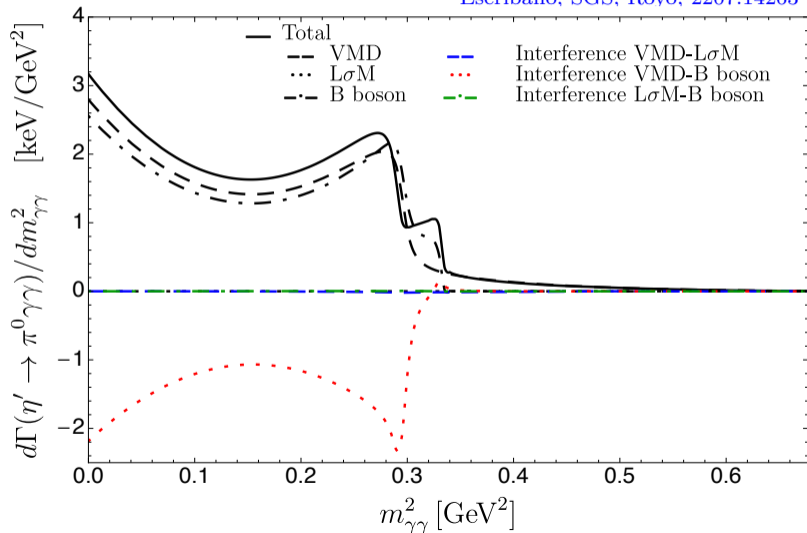
Individual contributions

Escribano, SGS, Royo, 2207.14263



Individual contributions

Escribano, SGS, Royo, 2207.14263



Interference phase between VMD and $L\sigma M$

