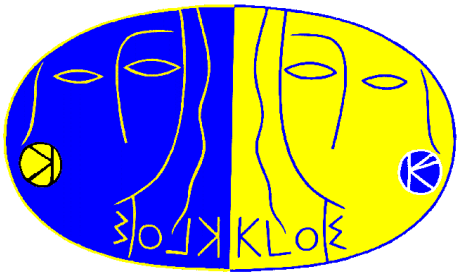


$\eta \rightarrow \pi^0\gamma\gamma$ analysis in KLOE experiment

Marcin Berlowski

Odbiory NCBJ 20.XII.2021

KLOE@NCBJ

- KLOE collaboration consists of 58 members from more then 25 institutions

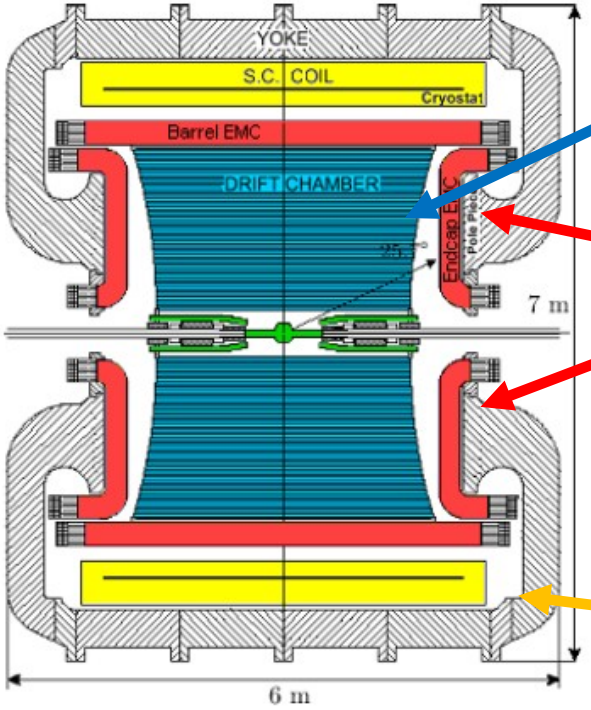
NCBJ:

- Wojciech Wiślicki (Institutional Board, Policy Board)
- Andrzej Kupść (Analysis Board, Policy Board)
- Marcin Berłowski (Technical Board)
- Wojciech Krzemień

- The presented results are based on my work for KLOE
- Moreover WW and AK are the internal collaboration referees for the analysis

DAFNE & KLOE

- DAFNE - e^+e^- collider @$\sqrt{s}=M_\phi$(1020 MeV) located in Frascati near Rome, Italy
- Two big data campaigns: 2001–06 and 2014-18 collecting ~8fb^{-1} → $2.4\cdot10^{10}$ ϕ
- The BR($\phi\to\eta\gamma$)=1.3% which gives >10^8 η's and the biggest in the world data sample of such decays collected at this energy in e^+e^- collider



Drift chamber:

- Gas mixture: 90% He, 10% isobutane
- Resolutions: σ_{xy}~150μm, σ_z~2mm, $\sigma p_t/p_t$<0.4% (45°<θ<135°), σ_v ~3mm

Electromagnetic calorimeter:

- Made of lead/scintillating fibers
- Covers 98% of solid angle
- Resolutions: $\frac{\sigma_E}{E}=\frac{5.7\%}{\sqrt{E(GeV)}}$, $\sigma_T=\frac{57\ ps}{\sqrt{E(GeV)}}\oplus 140$ ps

Magnetic field ~0.52 T

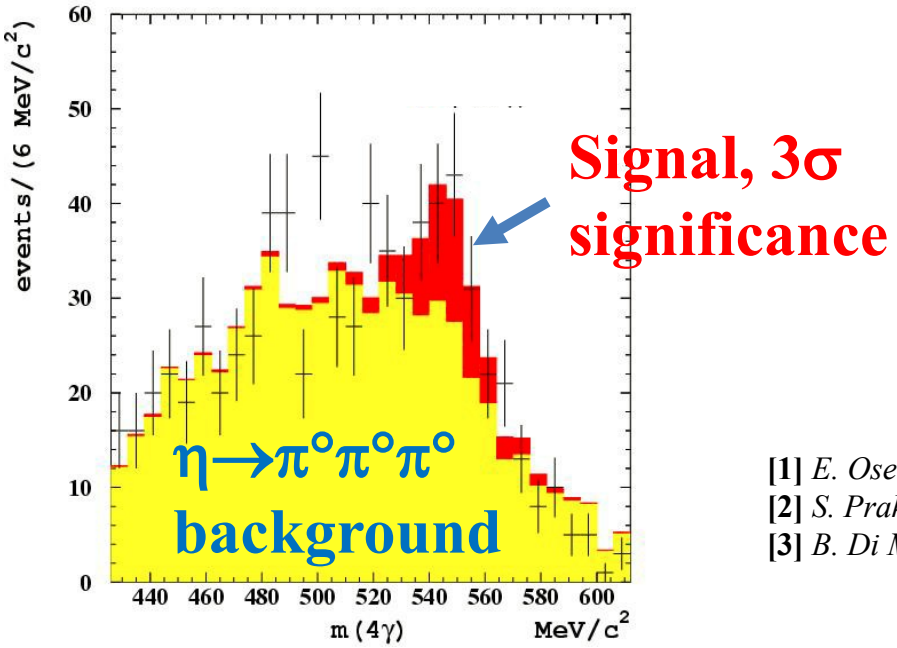
BR of $\eta \to \pi^\circ\gamma\gamma$

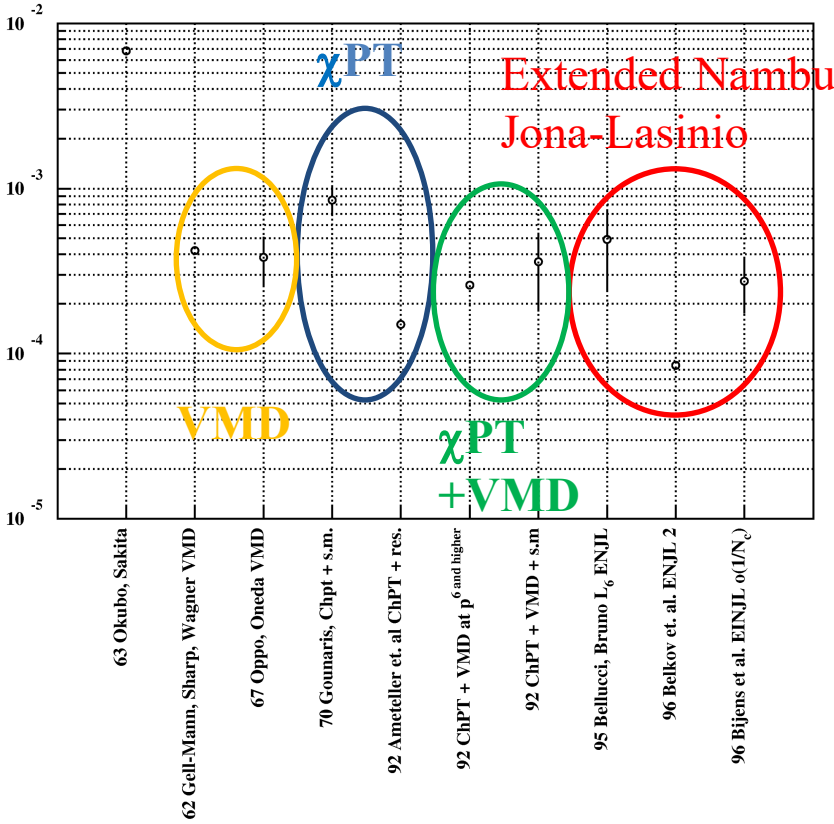
- BR discrepancy between experiments **[1]:**
  - AGS/Crystal Ball ($K^-p \to \Lambda\eta$) **[2]** (~1200 ev):

$$BR(\eta \to \pi^\circ\gamma\gamma) = (2.21 \pm 0.24_{stat} \pm 0.38_{syst}) \cdot 10^{-4}$$

  - KLOE ($\phi \to \eta\gamma$) **[3]** (63±28 ev), preliminary, based on L_{int}=450 pb^{-1}:

$$(0.84 \pm 0.27_{stat} \pm 0.14_{syst}) \cdot 10^{-4}$$





[1] *E. Oset et al, Phys. Rev. D 67, 073013 (2003),*
[2] *S. Prakhov et al., Phys. Rev. C 78 (2008) 015206*
[3] *B. Di Micco et al., Acta Phys. Slov. 56, 403 (2006),*

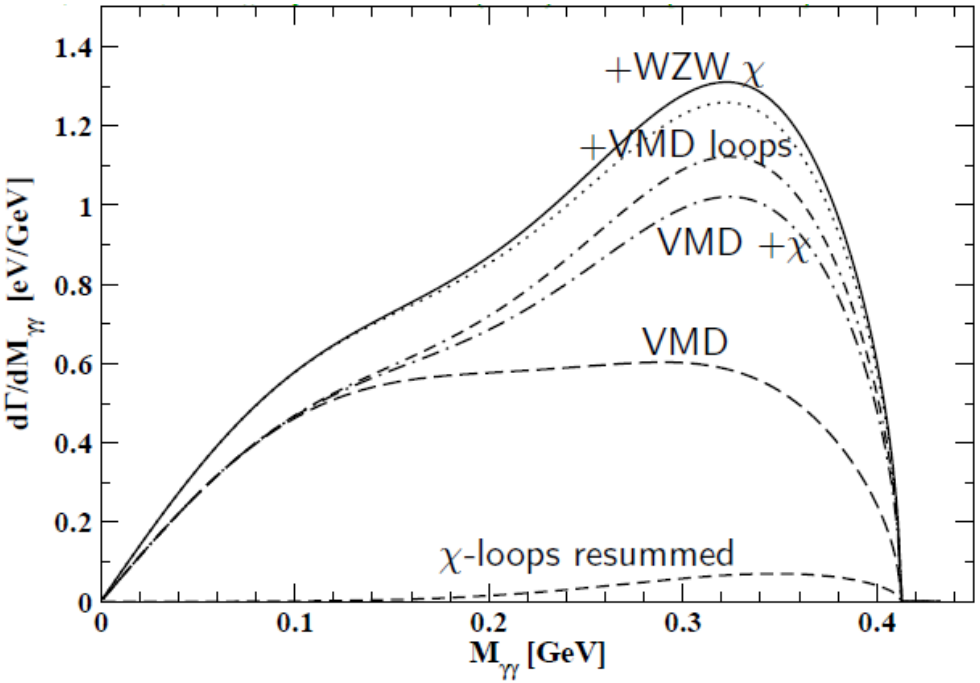
SM motivation

[Ll. Ametller et al. PLB 276(1) (1984)]

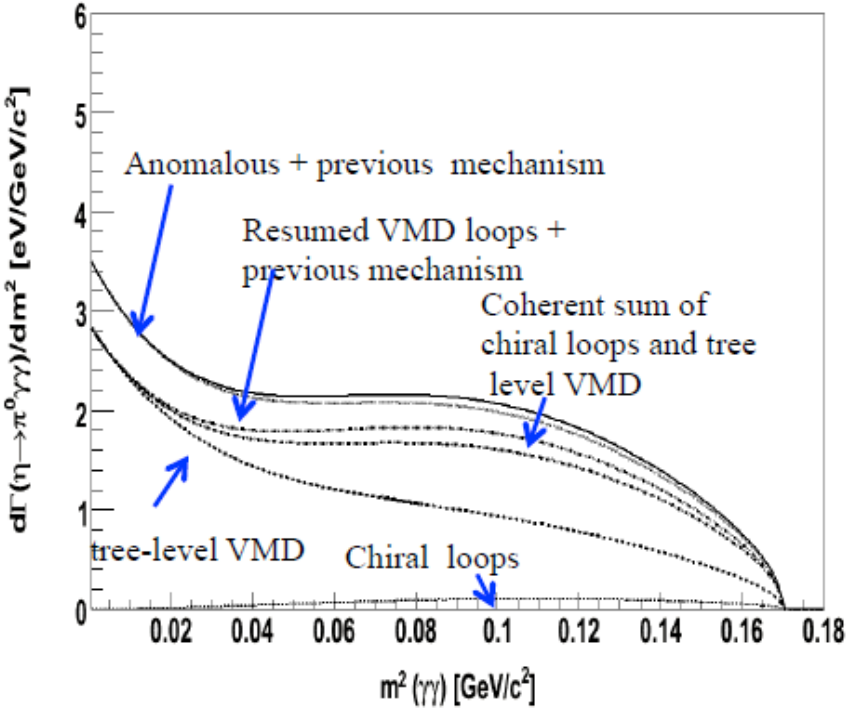
- χPT "golden mode": p^2 null, $p^4=0$ on the tree level & suppressed on 1-loop by G-parity and large kaon mass ⇒ p^6 dominates

G-parity is a combination of charge conjugation and a 180° rotation around the 2nd axis of isospin space.

- Coefficient values @ $O(p^6)$ and their signs must be determined from models
- $M(\gamma\gamma)$ or $M^2(\gamma\gamma)$ of non-π° photons can be used as a test of χPT and a wide range of chiral models, ex. VMD and LσM



[Phys. Rev. D 77 (2008) 073001]



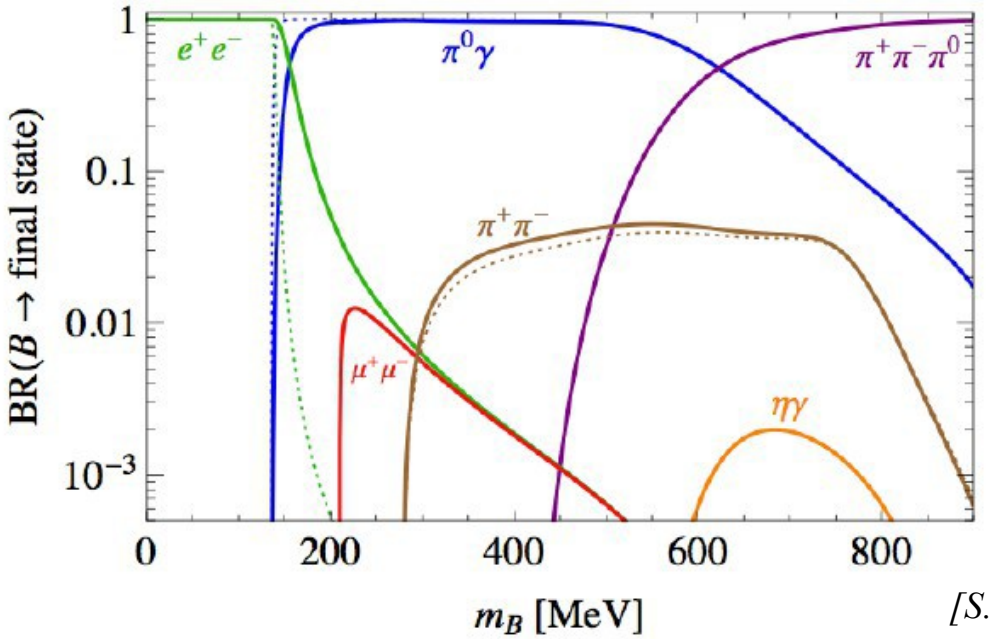
[Phys. Rev. D 67, 073013 (2003)]

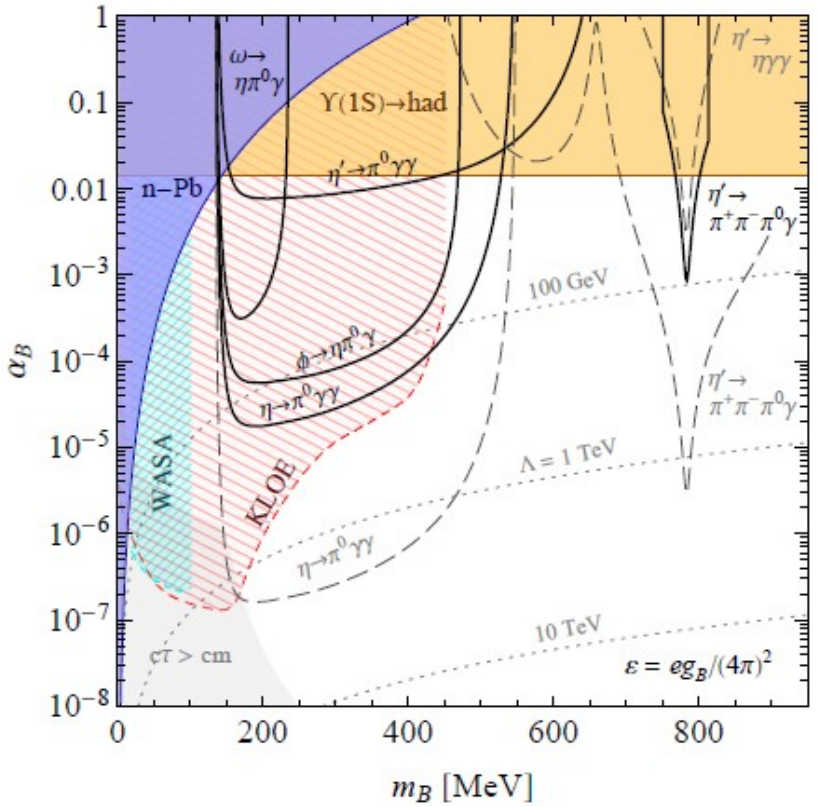
BSM motivation

- Search for a new physics - possible analog of the U boson, but B boson (leptophobic DM mediator) couples mostly to quarks, in the most basic model to baryon number via kinetic mixing term ε
- U boson searches don't exclude the existence of the B boson above m_{π^0} and this can still have an impact on the g-2 anomaly
- We can look for a B signature in the $M(\pi^0\gamma)$ produced in either $\phi \to B\eta$ or $\eta \to B\gamma$

$$\mathcal{L} = -\frac{1}{2}\varepsilon F^{\mu\nu}F'_{\mu\nu} = -\frac{g_B}{3}\bar{q}\gamma^\mu q B_\mu$$

$$\alpha_B = \frac{{g_B}^2}{4\pi}$$





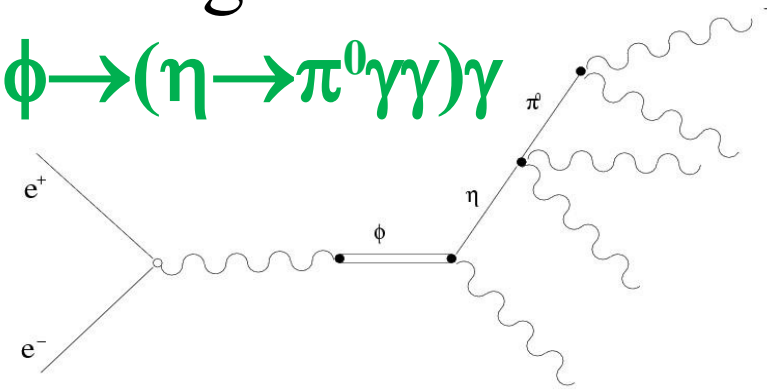
[S. Tulin Phys. Rev. D 89, 114008 (2014), arXiv:1404.4370]

$\phi \to \eta\gamma$ with $\eta \to \pi^\circ\gamma\gamma$

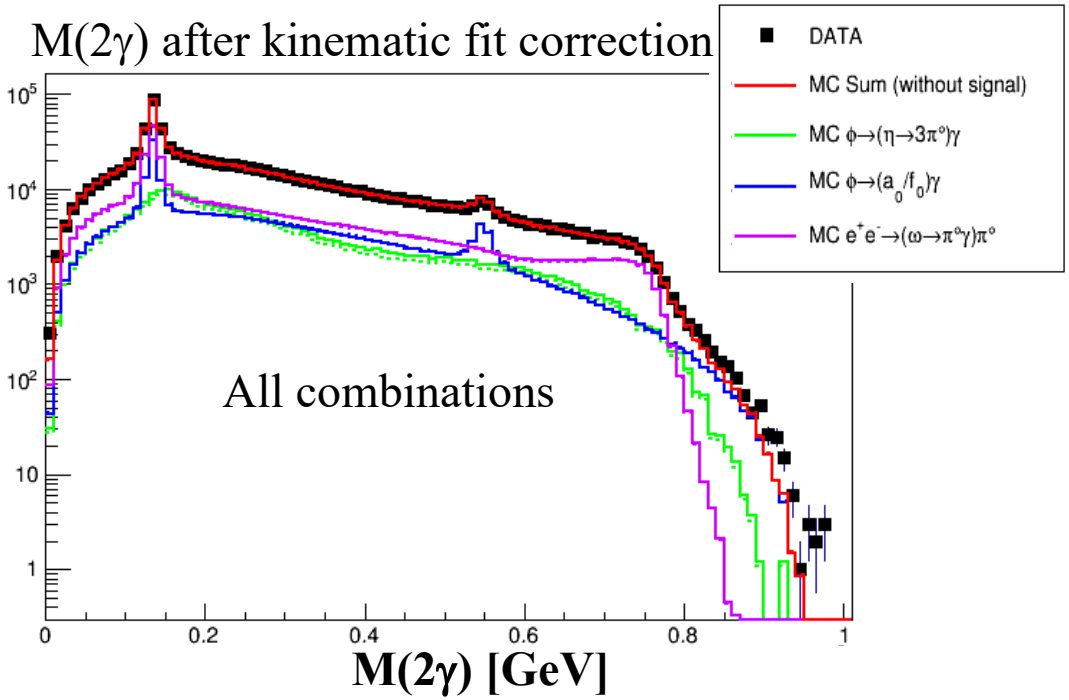
- A new analysis of old KLOE data, using ~4x larger data sample (1.7 fb^{-1})
- Clean case - 5 photon final state, no charged tracks
- Main background from: $\phi \to a_0\gamma \to \eta\pi^\circ\gamma$, $\phi \to (f_0 \to \pi^\circ\pi^\circ)\gamma$, $e^+e^- \to (\omega \to \pi^\circ\gamma)\pi^\circ$ and the most dangerous $\varphi \to (\eta \to 3\pi^\circ)\gamma$ with lost or merged photons
- Tagging $\eta \to \pi^\circ\gamma\gamma$ with the recoil photon of E = 363MeV from $\phi \to \eta\gamma$ decay
- Variables corrected by a kinematic fit with TOF of 5γ's and E & p conservation

Signal:

$\phi \to (\eta \to \pi^0\gamma\gamma)\gamma$

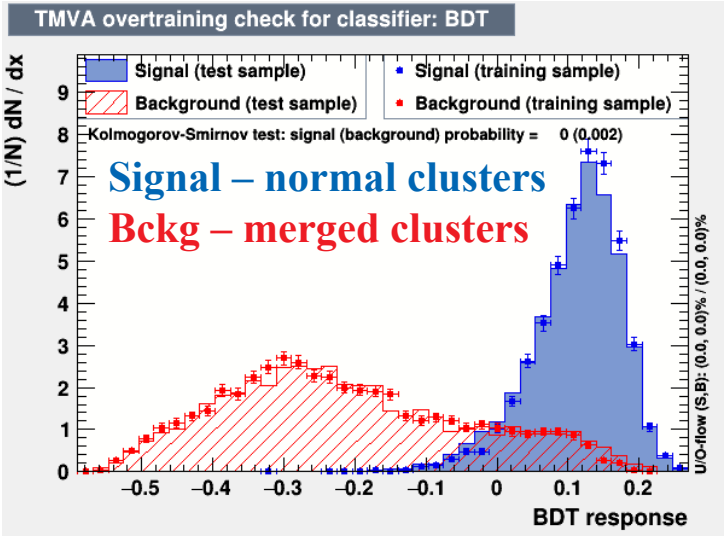


M(2γ) after kinematic fit correction

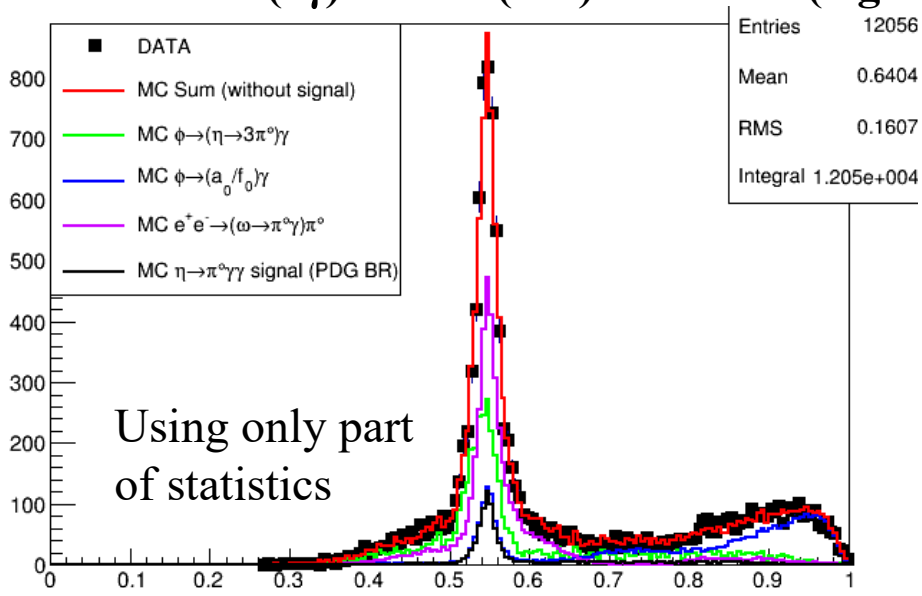


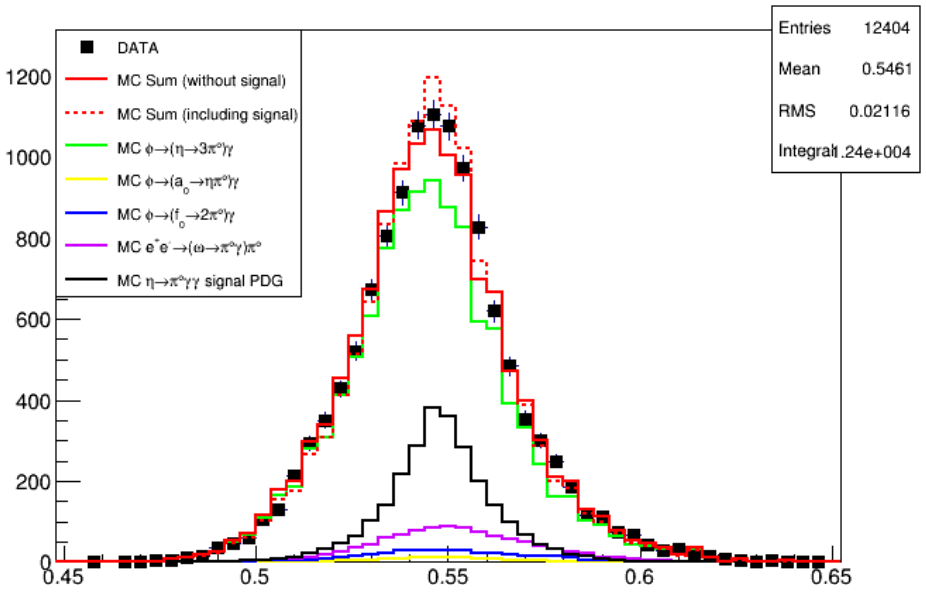
$\phi \to \eta\gamma$ with $\eta \to \pi^0\gamma\gamma$

- Additional selection criteria:
  - Kinematic fits with mass constrains either on $\pi^0\pi^0$ or $\eta\pi^0$ to filter a_0, f_0 and ω
  - BDT trained with MC using cell properties to suppress $\eta \to 3\pi^0$ with merged clusters
  - Dedicated kinfit for $\eta \to 3\pi^0$ cases when 2 photons were lost/undetected

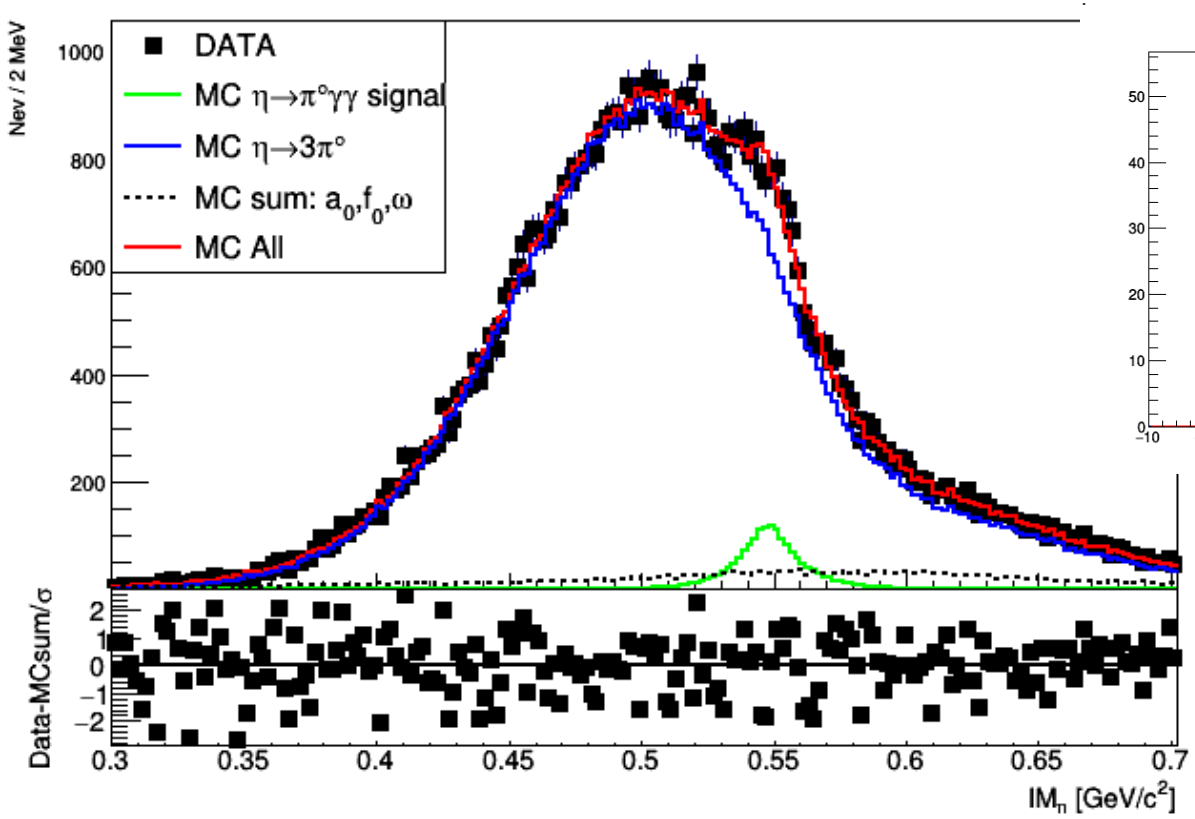


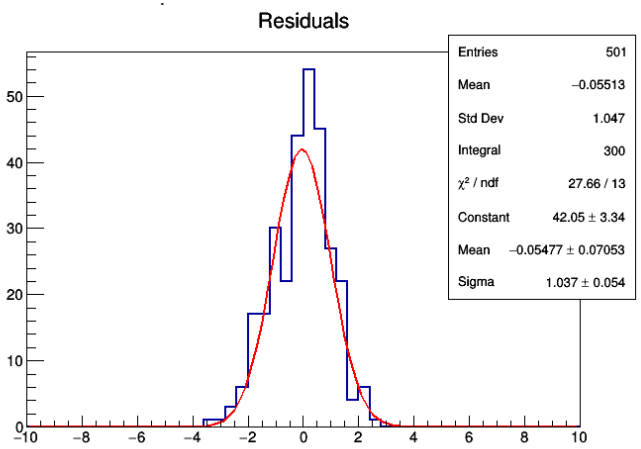
M(4γ) before (left) and after (right) constrained kinematic fit selection





3 component fit to IM($\pi^\circ\gamma\gamma$)





S/B ~ 2%

N_s ~ 1.4k

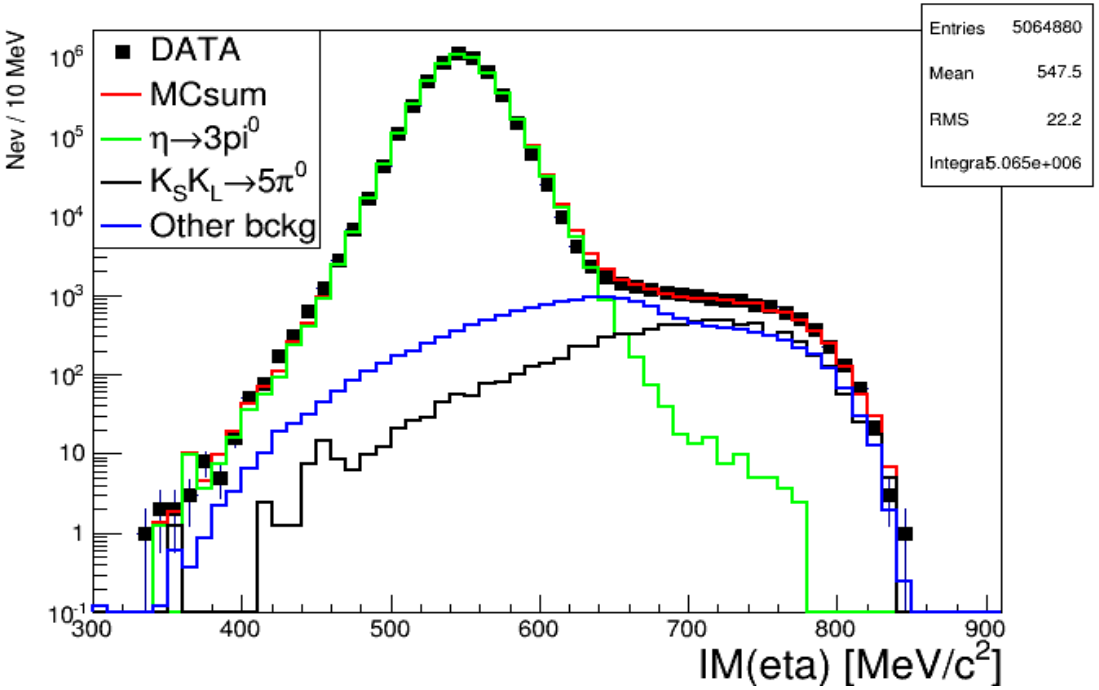
- $\eta\rightarrow 3\pi^\circ$, $\eta\rightarrow\pi^\circ\gamma\gamma$ signal and $\sum$ of non-3pi0 MC shapes fitted to data points
- Fit chi2/(ndf=98)=1.033 (fit_prob=39%)

How to calculate BR?

$$\frac{BR(\eta \to \pi^\circ \gamma\gamma)}{BR(\eta \to 3\pi^\circ)} = \frac{N_S/\varepsilon_S}{N_{3\pi^\circ}/\varepsilon_{3\pi^\circ}}$$

- Number of signal/3pi0 events taken from the fit results
- Channel efficiencies coming from MC
- $\eta \to 3\pi^\circ$ BR and it's error from PDG database
- Method used to avoid part of systematic errors
- BUT it depends on a very small and special subsample of $3\pi^\circ$'s with $\varepsilon_{3\pi^\circ} \sim (0.04)\%$
- We have other methods…

$\phi \rightarrow \eta\gamma \rightarrow 3\pi^{\circ}\gamma$ normalization

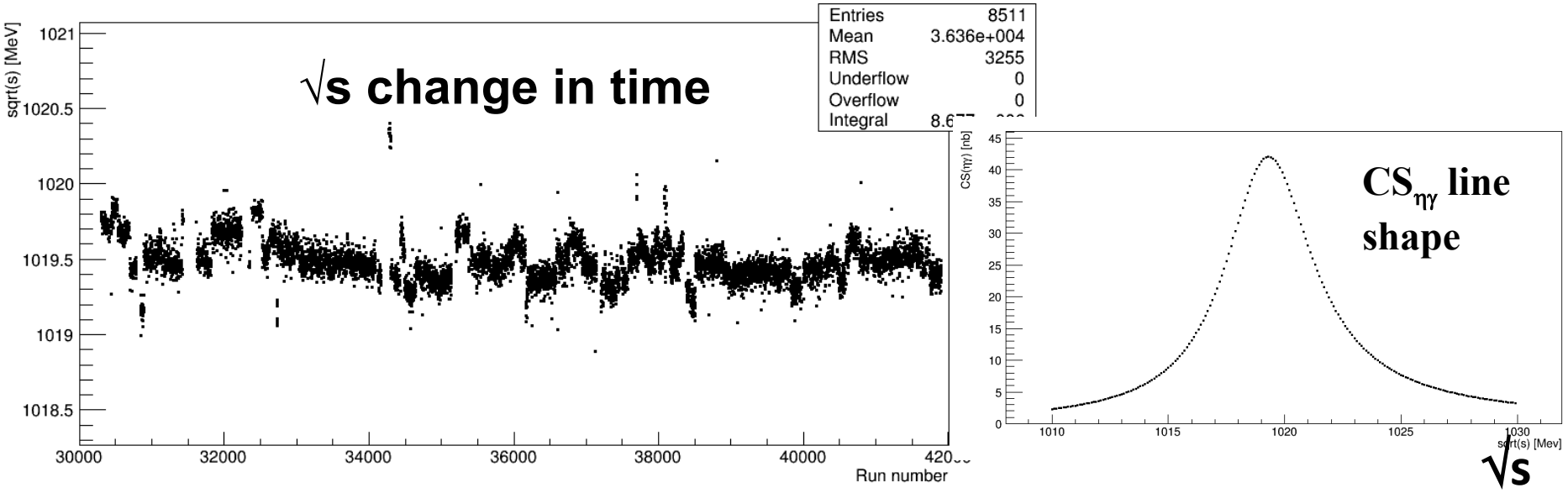


- Similar analysis as for $\eta \rightarrow \pi^0\gamma\gamma$ channel, but this time $\phi \rightarrow \eta\gamma \rightarrow 3\pi^{\circ}\gamma \rightarrow 7\gamma$ in the final state (BR~33%)
- Very pure channel, backgrounds well bellow 1%
- When used, can reduce part of systematic effects

Integrated luminosity

VLAB – $e^+e^- \rightarrow e^+e^-$ scattered at large angles

- Online measurement: 1722.1 pb^{-1}
- Offline with VLAB (constant CS assumed): 1729.6 pb^{-1}
- Correcting for $\sqrt{s}$ movement and $CS_{\eta\gamma}$: **1729.8 pb^{-1}**



$$BR(\eta \rightarrow \pi^{\circ}\gamma\gamma) = \frac{N_{sig}}{L_{int} \cdot \sigma(\eta\gamma) \cdot \varepsilon_{sig}}$$

N_{sig}, ε_{sig} from fit results

BR values

- Using 3 component fit results and normalizing to 5γ $\eta \to 3\pi^\circ$:
  - $BR(\eta \to \pi^\circ\gamma\gamma) = (1.12 \pm 0.11_{stat}) \cdot 10^{-4}$

- Using normalization to 7γ $\eta \to 3\pi^\circ$:

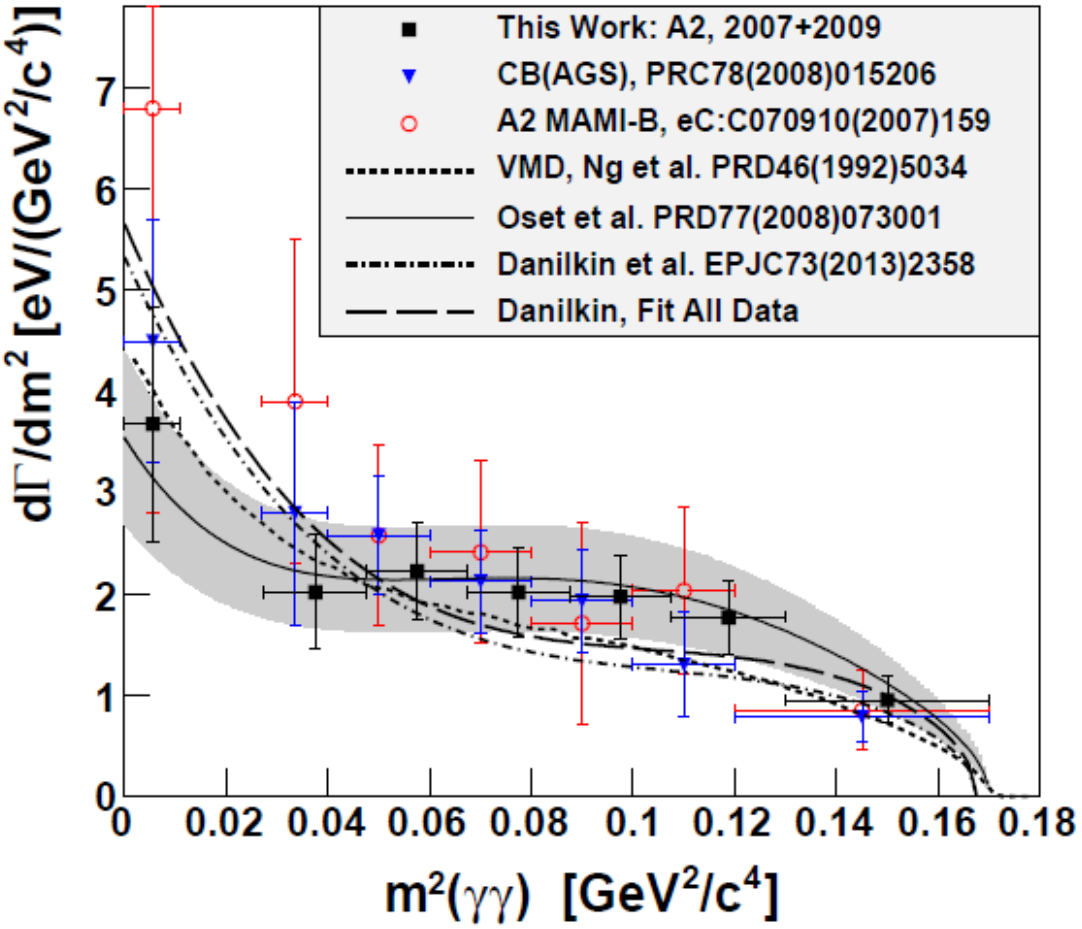
$$BR(\eta \to \pi^\circ\gamma\gamma) = (1.21 \pm 0.13_{stat}) \cdot 10^{-4}$$

- Using integrated luminosity measurement:

$$BR(\eta \to \pi^\circ\gamma\gamma) = (1.11 \pm 0.13_{stat} \pm 0.04_{lum}) \cdot 10^{-4}$$

Old KLOE prelim (68±23 ev):
$\mathbf{(0.84 \pm 0.27_{stat} \pm 0.14_{syst}) \cdot 10^{-4}}$
PDG (AGS08, ~1.5k ev):
$\mathbf{(2.21 \pm 0.24_{stat} \pm 0.38_{syst}) \cdot 10^{-4}}$

$d\Gamma/dM^2(\gamma\gamma)$ A2 MAMI plot

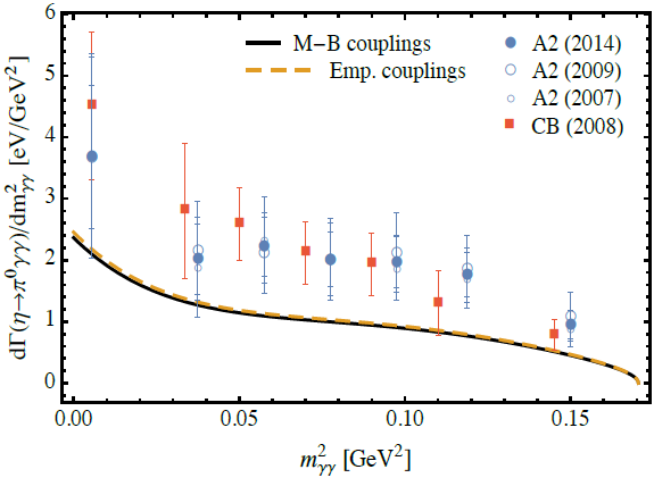


A2 MAMI
PRC 90 (2014) 025206

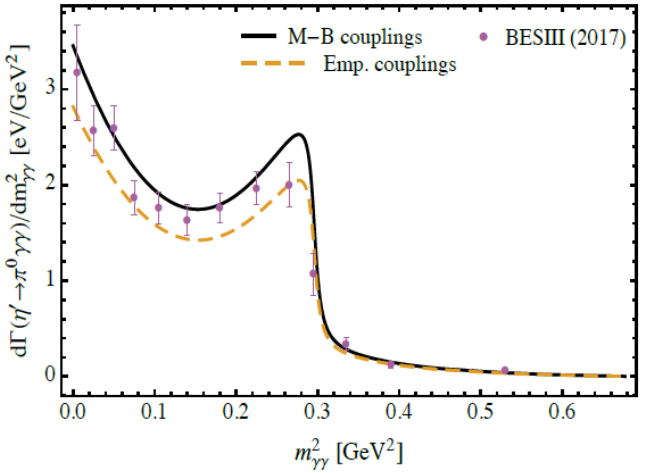
- $\gamma\gamma$ pair of non-π° photons in $\eta \rightarrow \pi^\circ\gamma\gamma$

New $\eta \to \pi^\circ\gamma\gamma$ prediction

- Coming from Escribano et al. *[**PRD** 102 (2020) 034026]*
- Claims that previous calculations were overestimated by a factor of two due to not taking into account the same non-π° two photons in the final state when relating decay amplitude with it's width
- Why we should believe them? They can predict $\eta' \to \pi^\circ\gamma\gamma$ using the same method that matches BESIII data *[**PRD** 96 (2017) 012005]*.

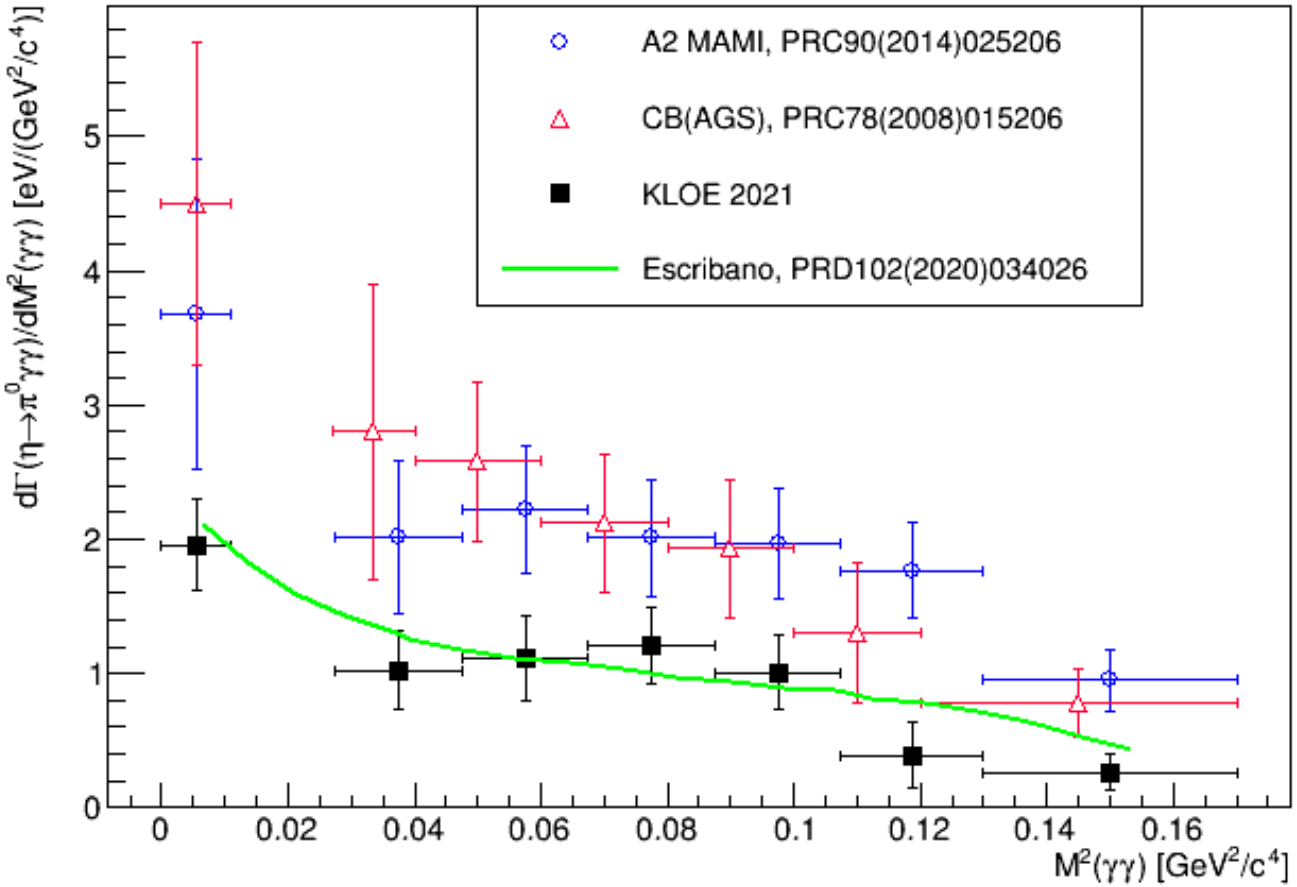


(a) $\eta \to \pi^0\gamma\gamma$ decay.



(b) $\eta' \to \pi^0\gamma\gamma$ decay.

dΓ/dM²(γγ) in KLOE



- Separate fits to M(π°γγ) in M²(γγ) slices
- Bin 0.011-0.0275 GeV²/c⁴ missing due to π°π° veto
- KLOE with statistical error only, other experiments using total
- Good agreement with the latest theoretical predictions

BR(η→π°γγ) comparison

- CB (2008): $BR(\eta\to\pi^\circ\gamma\gamma)=(2.21\pm0.24_{stat}\pm0.47_{syst})\cdot10^{-4}$
- A2 (2014): $(2.56\pm0.24_{tot})\cdot10^{-4}$

- **KLOE 2021:**
  - From integration of $d\Gamma/dM^2$ (missing bin lineary interpolated):

    $(1.40 \pm 0.14_{stat})\cdot10^{-4}$

  - Integrating $d\Gamma/dM^2$, normalizing to 7γ:

    $\mathbf{(1.30 \pm 0.13_{stat})\cdot10^{-4}}$

  - From the full spectrum (NOTE that we don't have bin around M(π°) here!):

    $\mathbf{(1.12 \pm 0.11_{stat})\cdot10^{-4}}$ **or** $\mathbf{(1.21 \pm 0.11_{stat})\cdot10^{-4}}$ normalizing to 7γ

- Escribano et al. (2020) predicts $\mathbf{BR_{theo}=1.35(8)\cdot10^{-4}}$

Conclusions

- Well established analysis methods
- Not only BR, but also $d\Gamma/dM^2(\gamma\gamma)$ shows half of expected (from the last experiments at least) contribution
- Good agreement to the latest calculations
- Proper evaluation of errors in $d\Gamma/dM^2(\gamma\gamma)$ needed
- Systematics determination ongoing
- Preparation of paper draft in progress

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THANK YOU for your attention!!!