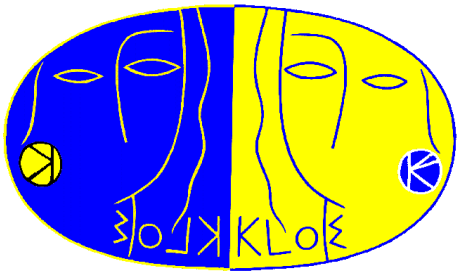


Measurement of $\eta \to \pi^{\circ}\gamma\gamma$ decay in KLOE experiment

Marcin Berlowski

Odbiory NCBJ 16.XII.2022

Outline

- KLOE collaboration
- KLOE detector
- Past experiments and current theory
- $\eta \rightarrow \pi^{\circ}\gamma\gamma$ Branching Fraction measurement
- $d\Gamma(\eta \rightarrow \pi^{\circ}\gamma\gamma)/dM^2(\gamma\gamma)$ distribution
- Summary

KLOE@NCBJ

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

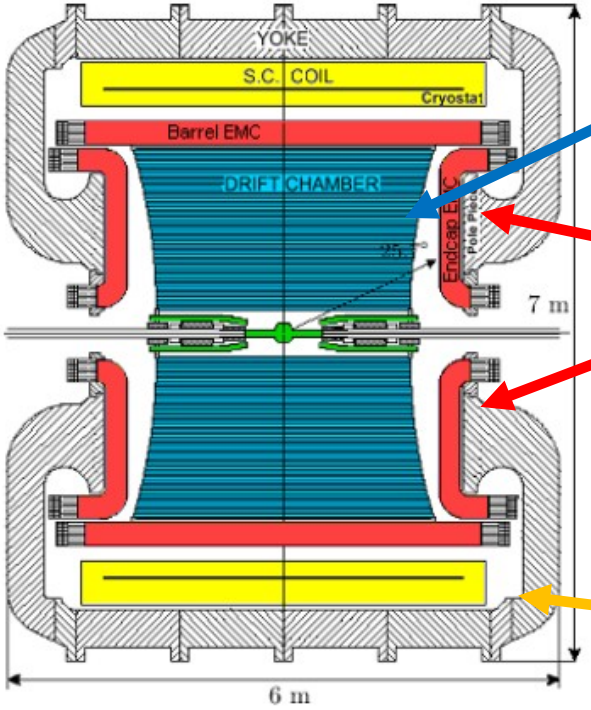
NCBJ:

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

- 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} → 2.4·10^{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]** (~500 ev):

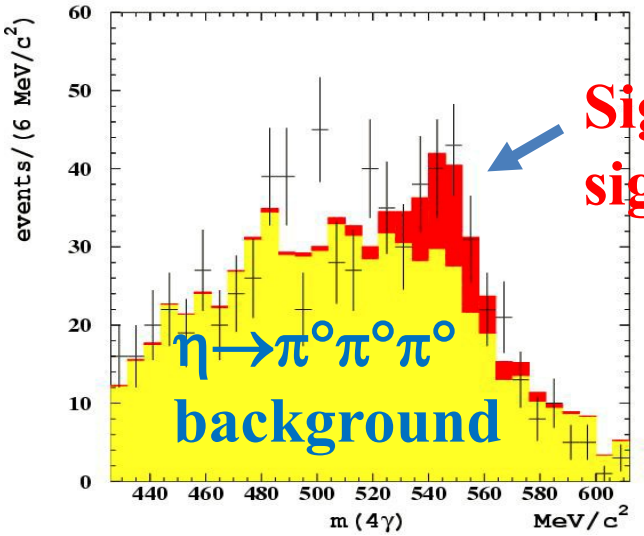
$$BR(\eta \to \pi^\circ\gamma\gamma) = (2.21 \pm 0.24_{stat} \pm 0.38_{syst}) \cdot 10^{-4}$$

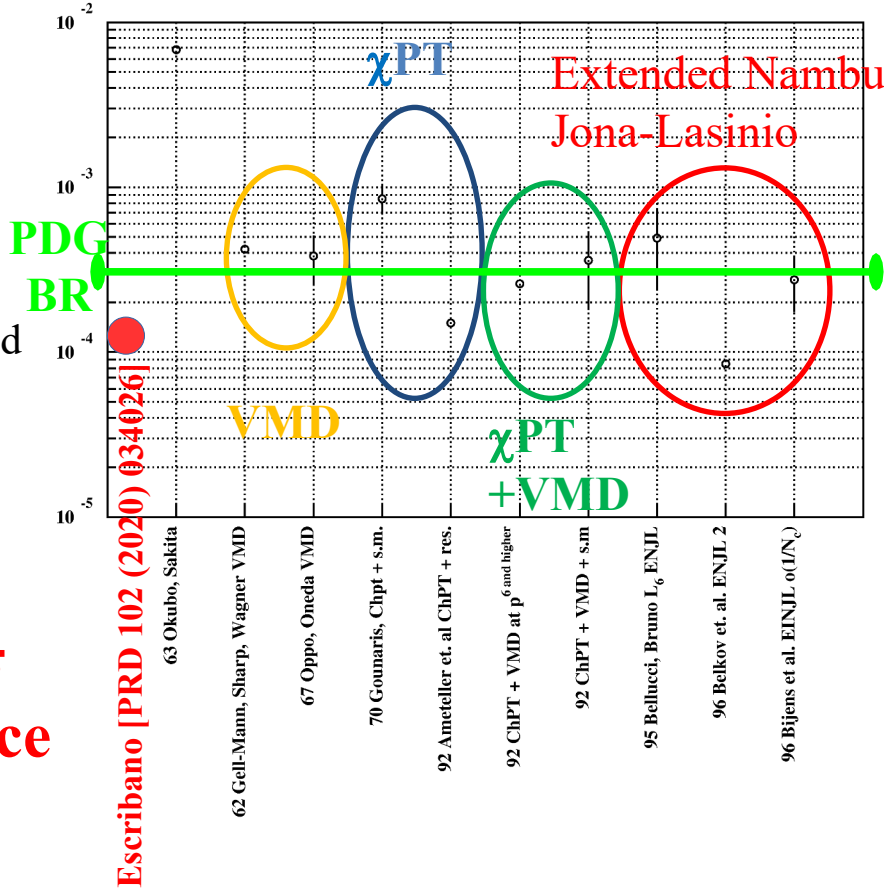
  - A2/Crystal Ball **[3]** (~1200 ev) calc. from Γ:

$$(2.56 \pm 0.24_{tot}) \cdot 10^{-4}$$

  - KLOE ($\phi \to \eta\gamma$) **[4]** (63±28 ev), preliminary, based on L_{int}=450 pb^{-1}:

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





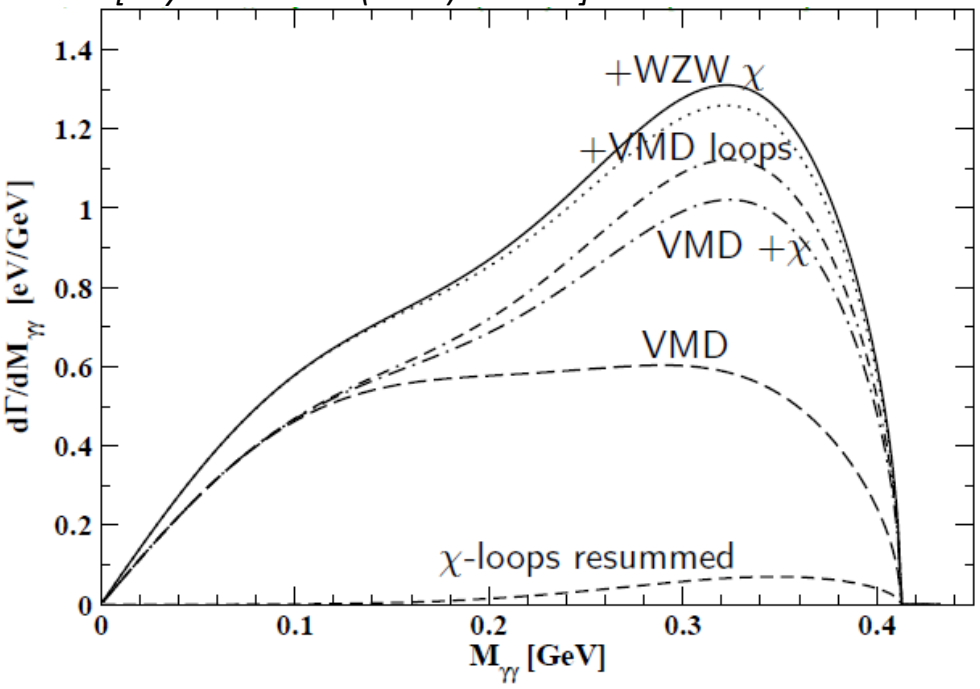
[1] *E. Oset et al., Phys. Rev. D 67 (2003) 073013*
[2] *S. Prakhov et al., Phys. Rev. C 78 (2008) 015206*
[3] *B.M.K. Nefkens et al., Phys. Rev. C 90 (2014) 025206*
[4] *B. Di Micco et al., Acta Phys. Slov. 56, 403 (2006)*

$\eta \to \pi^\circ\gamma\gamma$ χPT input

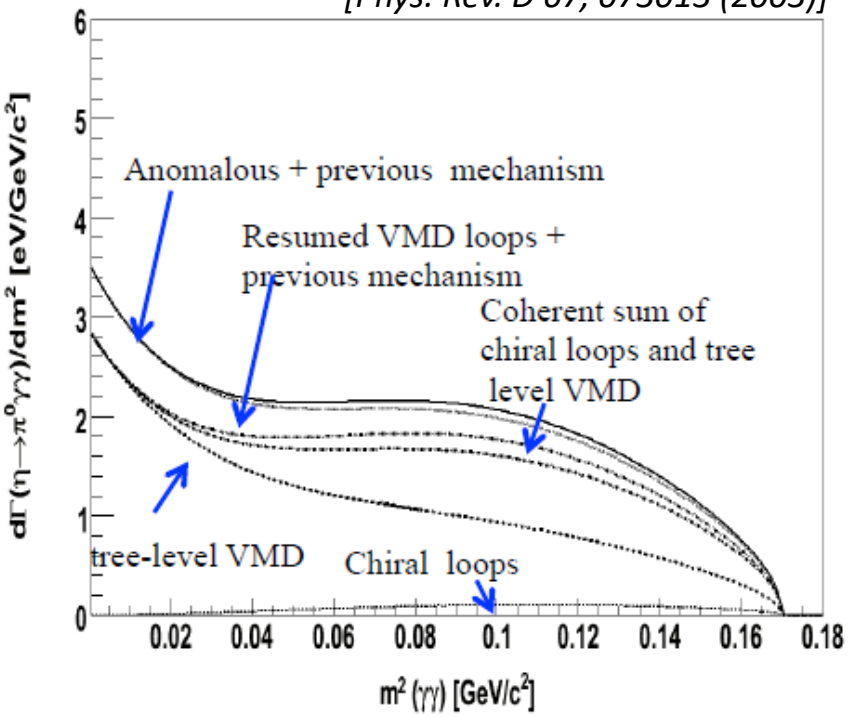
[Ll. Ametller et al. PLB 276(1) (1984)]

- χPT "golden mode": p^2 null, $p^4=0$ on the tree level $\Rightarrow$ p^6 dominates
- Coefficient values @ $O(p^6)$ and their signs must be determined from models
- $\gamma\gamma$ invariant mass of photons that are not coming from π° in $\eta \to \pi^\circ\gamma\gamma$ decay can be used as a test of theoretical models

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

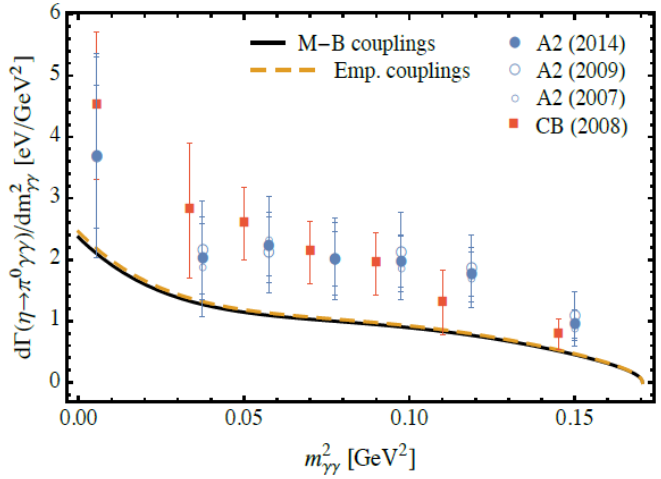


[Phys. Rev. D 67, 073013 (2003)]

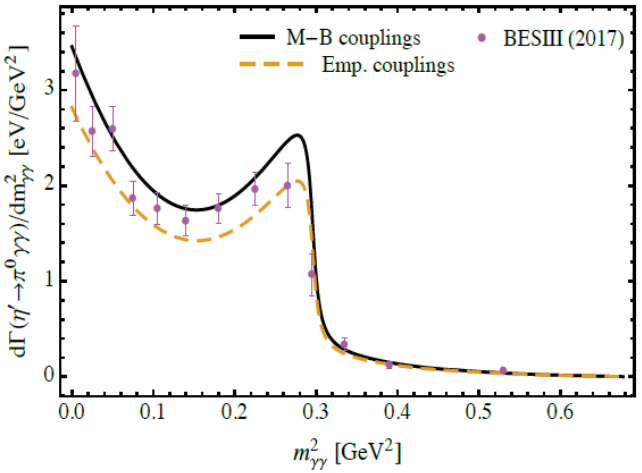


New $\eta \to \pi^\circ\gamma\gamma$ prediction

- Escribano et al. *[PRD 102 (2020) 034026]*
- The possible explanation for the discrepancy with other theory predictions is that previous calculations could be 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 to its width
- Why we should believe them? Their prediction for $\eta' \to \pi^\circ\gamma\gamma$ well agrees with experimental data of BESIII *[PRD 96 (2017) 012005]*
- Predicts $BR(\eta \to \pi^\circ\gamma\gamma) = 1.30(8) \cdot 10^{-4}$



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

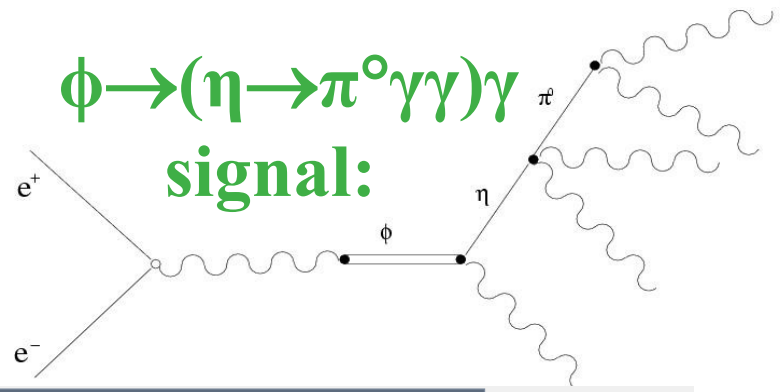


(b) $\eta' \to \pi^0\gamma\gamma$ decay.

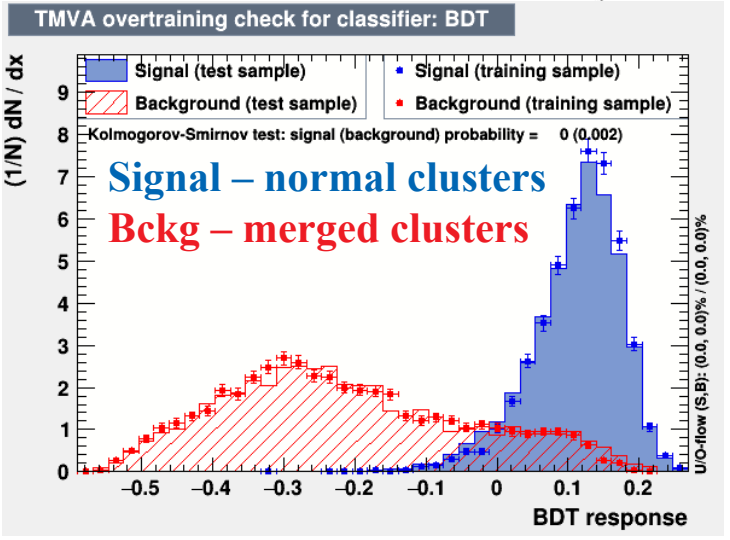
Data/MC sample

- New analysis of KLOE data, using 4x larger independent data sample (1.7 fb^{-1})
- Looking for 5 prompt photons in the final state
- MC simulation of radiative ϕ decays with 10x larger luminosity
- Main backgrounds from: $\phi\to(a_0\to\eta\pi^\circ)\gamma$, $\phi\to(f_0\to\pi^\circ\pi^\circ)\gamma$, $e^+e^-\to(\omega\to\pi^\circ\gamma)\pi^\circ$ and $\phi\to(\eta\to3\pi^\circ)\gamma$ with lost or/and merged photons

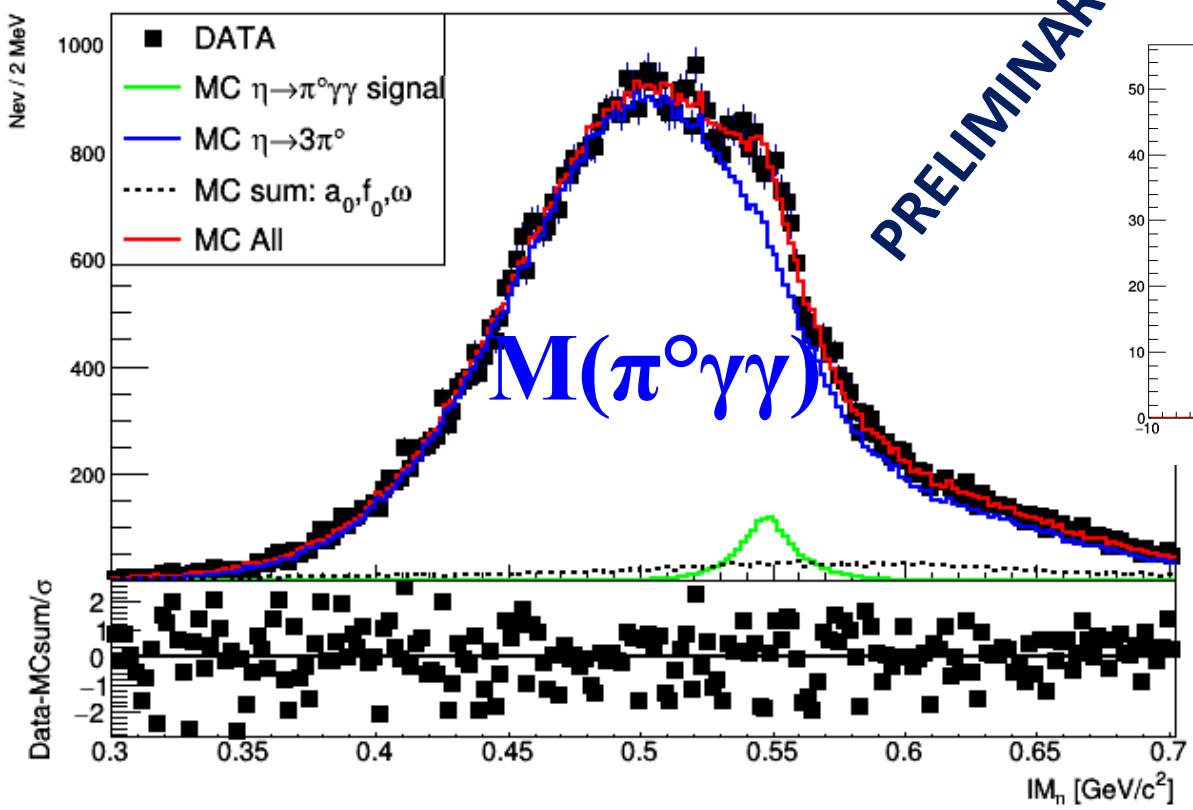
$\phi\to(\eta\to\pi^\circ\gamma\gamma)\gamma$ signal:

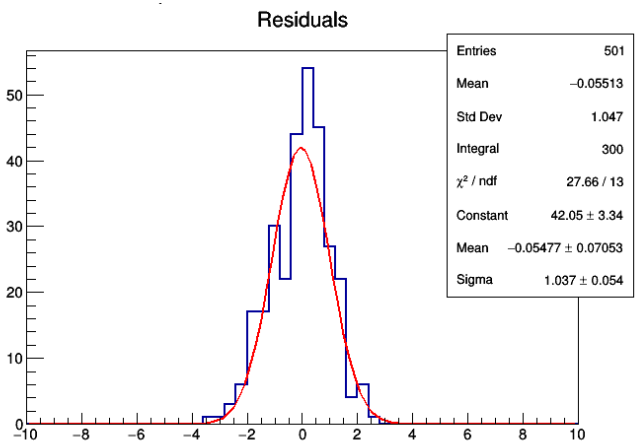


- **A few analysis features:**
  - Photons of >20 MeV in 25°-155° cone
  - Identifying recoil photon originating from $\phi\to\eta\gamma$ decay by its energy (363 MeV)
  - Resolution improved with kinematic fit with TOF of 5γ's and E & p conservation
  - Removing a_0, f_0 and ω with kinematic fits using mass constrains (either on $\pi^\circ\pi^\circ$ or $\eta\pi^\circ$)
  - Dedicated Multivariate Data Analysis using Boosted Decision Trees for merged clusters based on their shape, trained with MC



3 component fit to final M(π°γγ) distribution

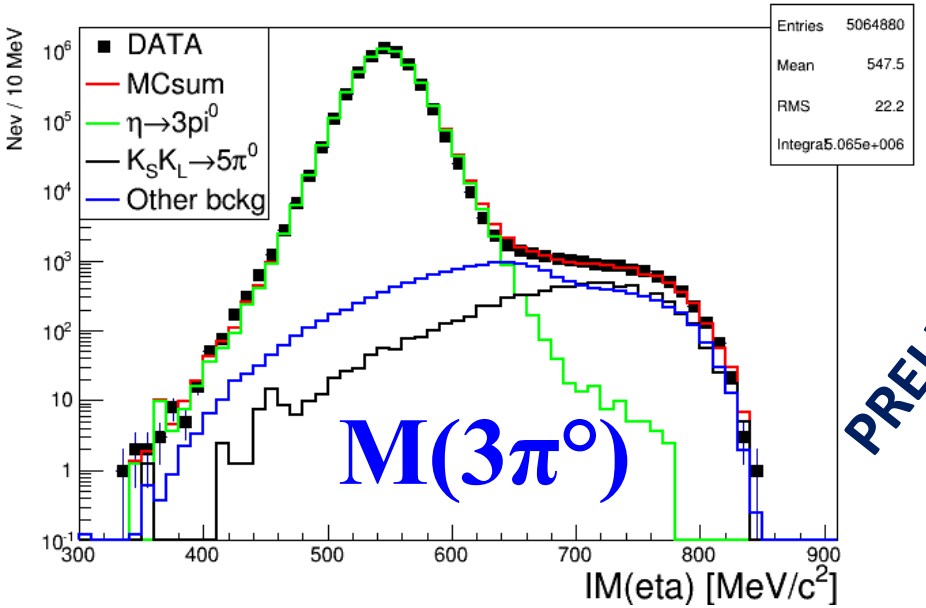


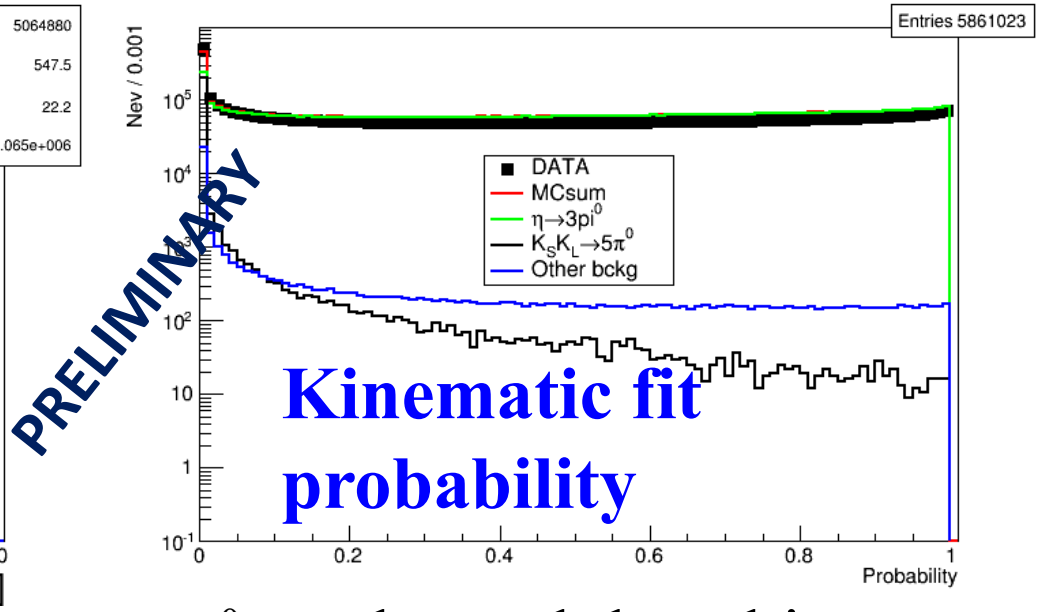


S/B ~ 2.5%
N_s ~ 1.2k
Prob ~ 2%
Eff_s ~ 15%

- MC contributions fitted to data points

Normalization to $\eta \to 3\pi^0$





- Similar analysis as for $\eta \to \pi^0\gamma\gamma$ channel, but this time 7γ (6-8γ) in the final state (BR~33%)
- Kinematic fit used in order to improve resolution
- Very pure channel, backgrounds well bellow 1%
- When used as a normalization channel, can reduce part of systematic effects

BR(η→π°γγ) value

- Using normalization to $\phi \to (\eta \to 3\pi^\circ)\gamma \to 7\gamma$

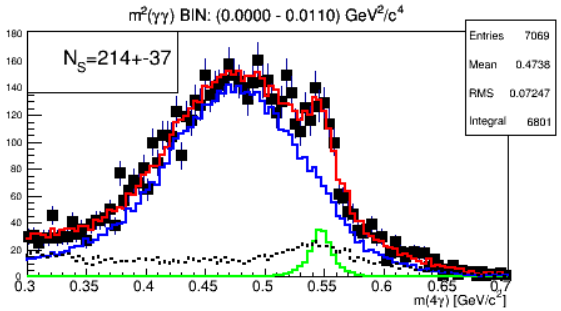
$$\mathbf{BR(\eta \to \pi^\circ\gamma\gamma) = (1.21 \pm 0.13_{stat} \pm 0.25_{syst}) \cdot 10^{-4}}$$

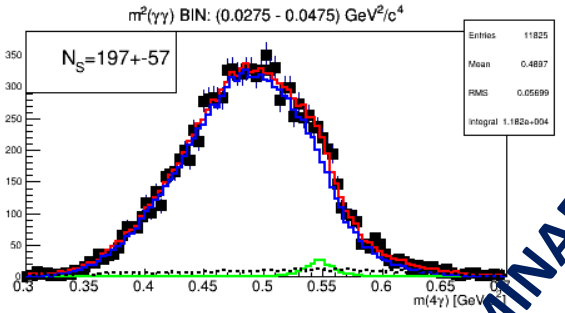
- The main sources for systematic uncertainty come from 5 prompt photon selection, analysis cuts and normalization
- Last checks on systematics are ongoing

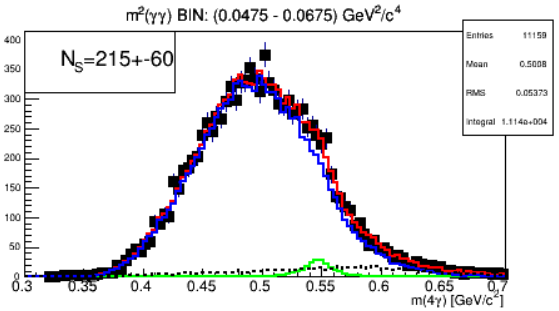
- Escribano et al. *[PRD 102 (2020) 034026]* paper predicts BR=1.30(8)·10^{-4}

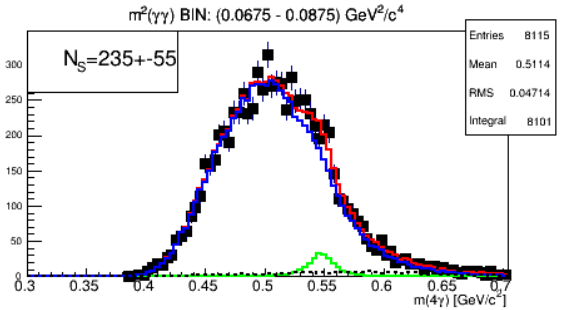
Old KLOE prelim (68±23 ev):
$\mathbf{(0.84 \pm 0.27_{stat} \pm 0.14_{syst}) \cdot 10^{-4}}$
PDG (AGS08, ~1.5k ev):
$\mathbf{(2.21 \pm 0.24_{stat} \pm 0.38_{syst}) \cdot 10^{-4}}$

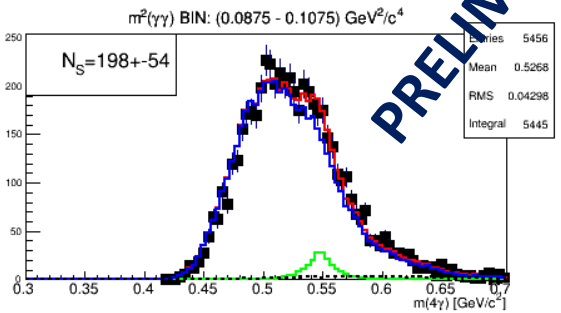
$\pi^\circ\gamma\gamma$ fits in $M^2(\gamma\gamma)$ slices

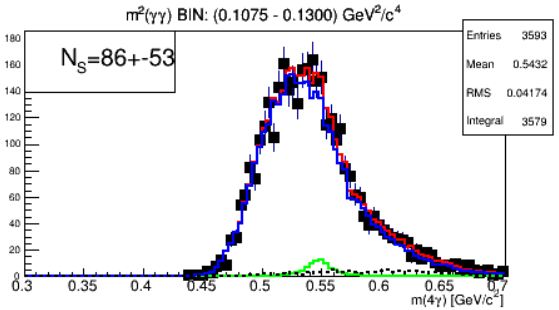


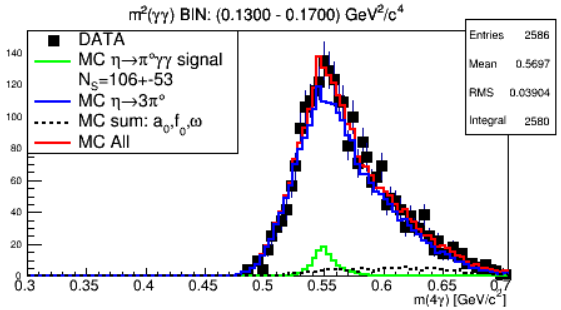








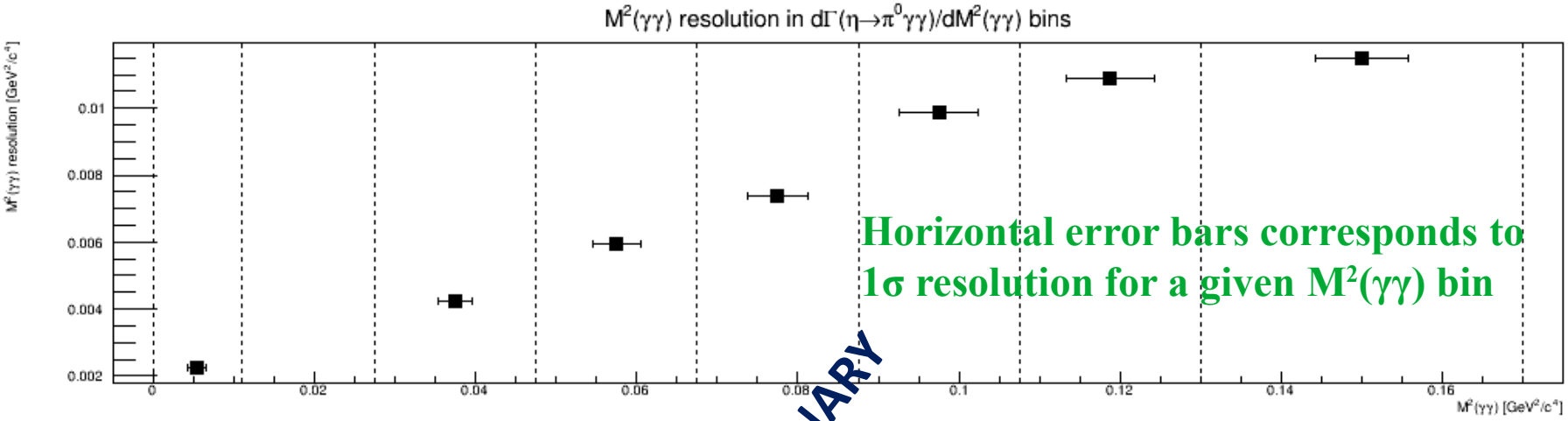


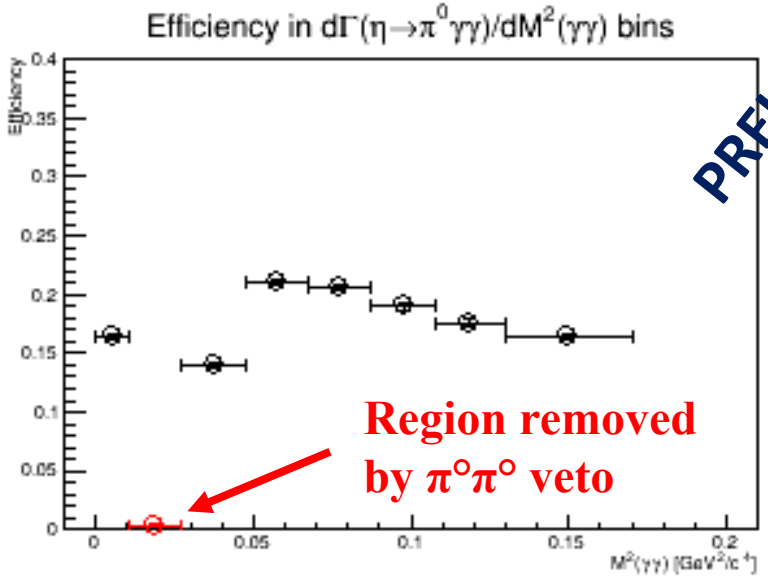


PRELIMINARY

- Separate fits of $M(\pi^0\gamma\gamma)$ in bins of $M^2(\gamma\gamma)$, number of signal events extracted from the fit presented in legend
- Bin 0.011-0.0275 GeV^2/c^4 missing due to $\pi^\circ\pi^\circ$ veto (for events $\phi\rightarrow f_0(980)\gamma$, with $f_0(980)\rightarrow\pi^0\pi^0$ and $e^+e^-\rightarrow\omega\pi^0$ with $\omega\rightarrow\pi^0\gamma$)

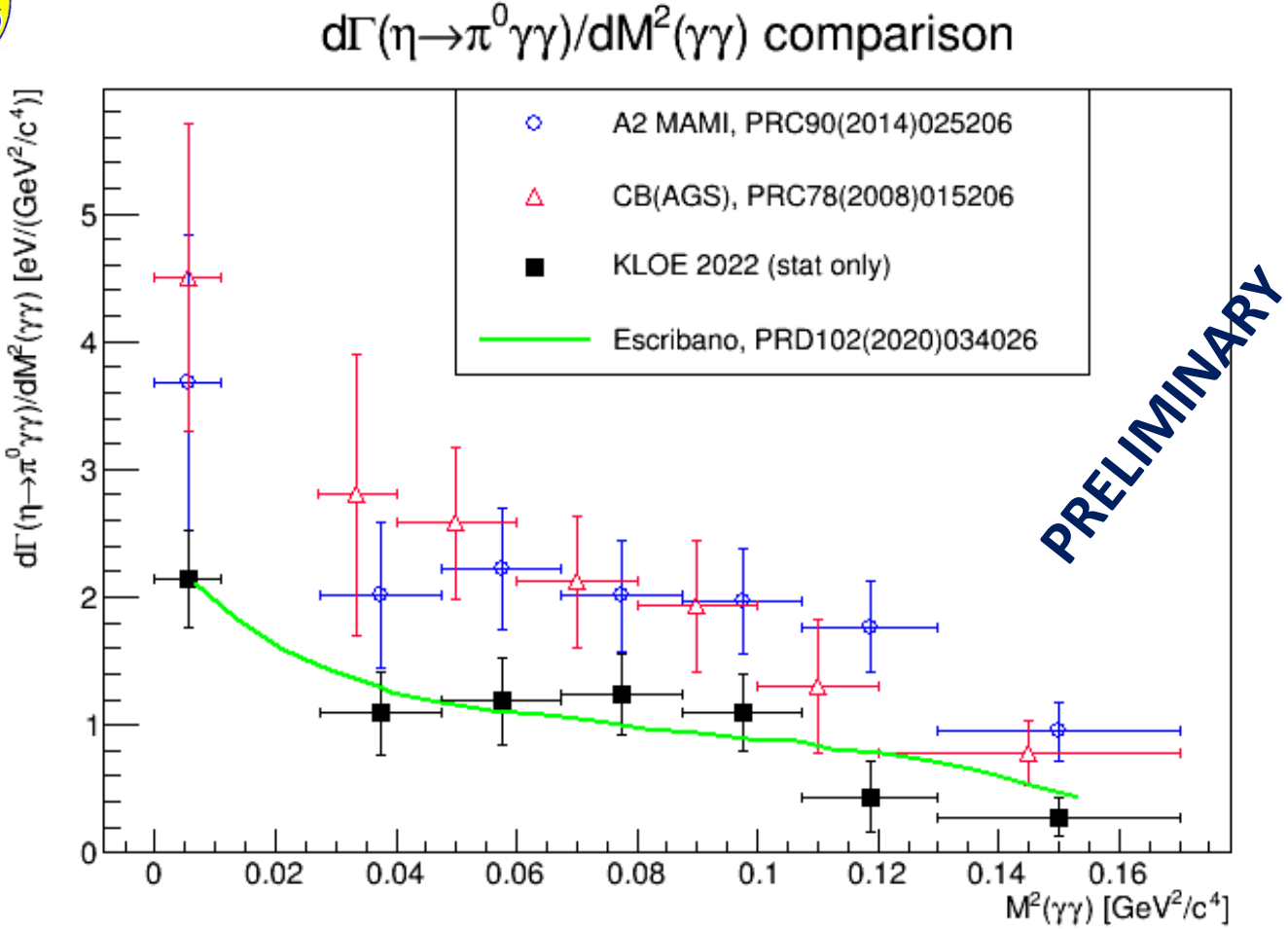
$M^2(\gamma\gamma)$ resolution and signal efficiency





PRELIMINARY

- Resolution and signal efficiency for $M^2(\gamma\gamma)$ bins based on MC studies



- Here KLOE with stat error only, other experiments with total error
- From integration of $d\Gamma/dM^2$ (missing bin lineary interpolated):

$$\mathbf{(1.30 \pm 0.13_{stat})\cdot 10^{-4}}$$

Summary and conclusions

- Well established analysis methods
- New KLOE value of BR($\eta \to \pi^\circ\gamma\gamma$) confirms the discrepancy seen with the previous, preliminary KLOE result
- The newest theory matches well KLOE $d\Gamma/dM^2(\gamma\gamma)$ distribution as well as the BR value
- Systematics determination ongoing
- Preparation of paper draft in progress

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THANK YOU for your attention!!!

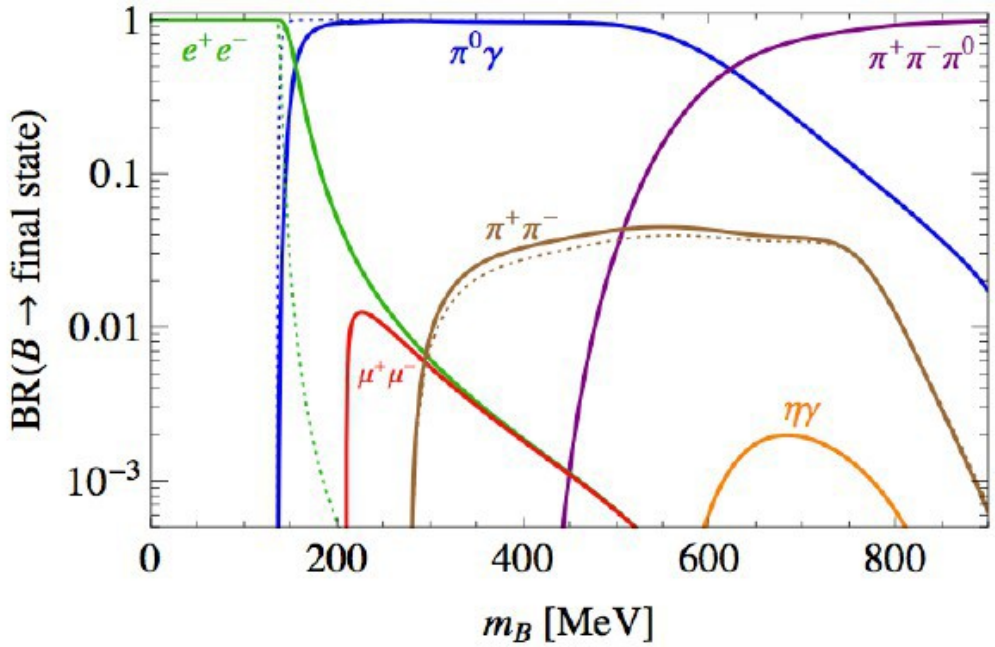
BACKUP

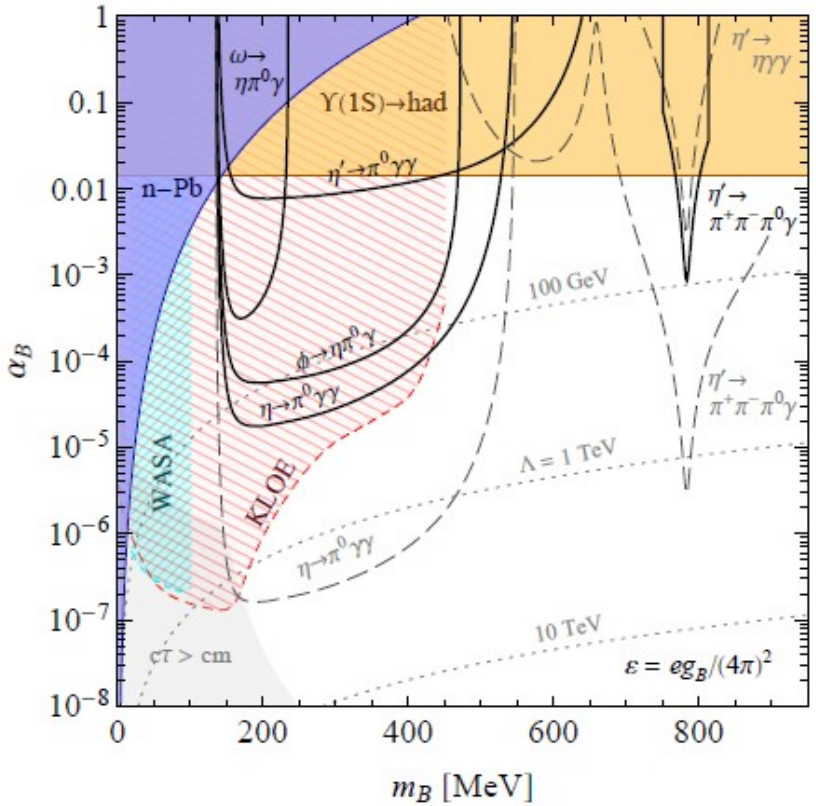
Dark matter searches

- 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 $\eta \to B\gamma$

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

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





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