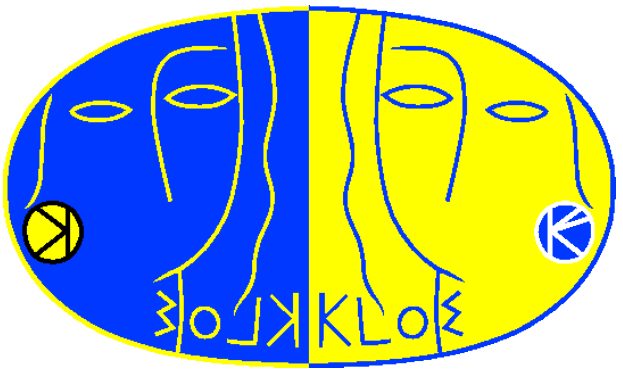
η/η' decays with KLOE

Marek Jacewicz, LNF-INFN Frascati

on behalf of the KLOE Collaboration



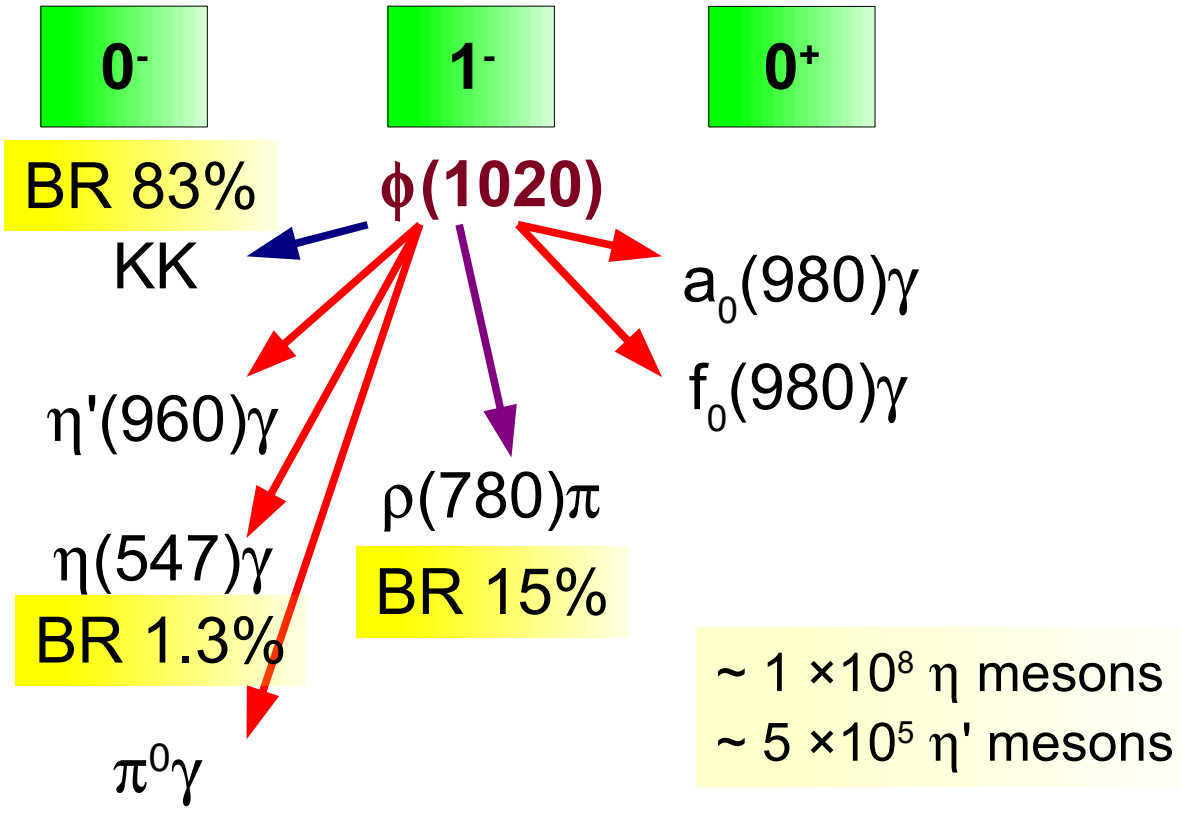
DAFNE collider in Frascati

e^+e^- collider @ $\sqrt{s} = m_\phi = 1.019$ GeV

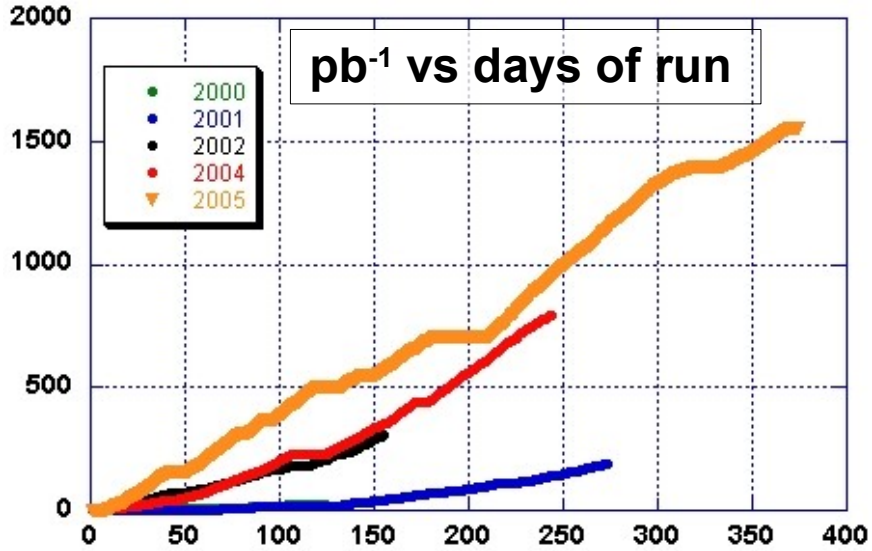
in KLOE runs ~2.5 fb^{-1} collected

This translates to ~8×10^9 ϕ mesons

Also collected 240 pb^{-1} @ 1 GeV "off-peak"



~ 1 ×10^8 η mesons
~ 5 ×10^5 η' mesons



KLOE experiment

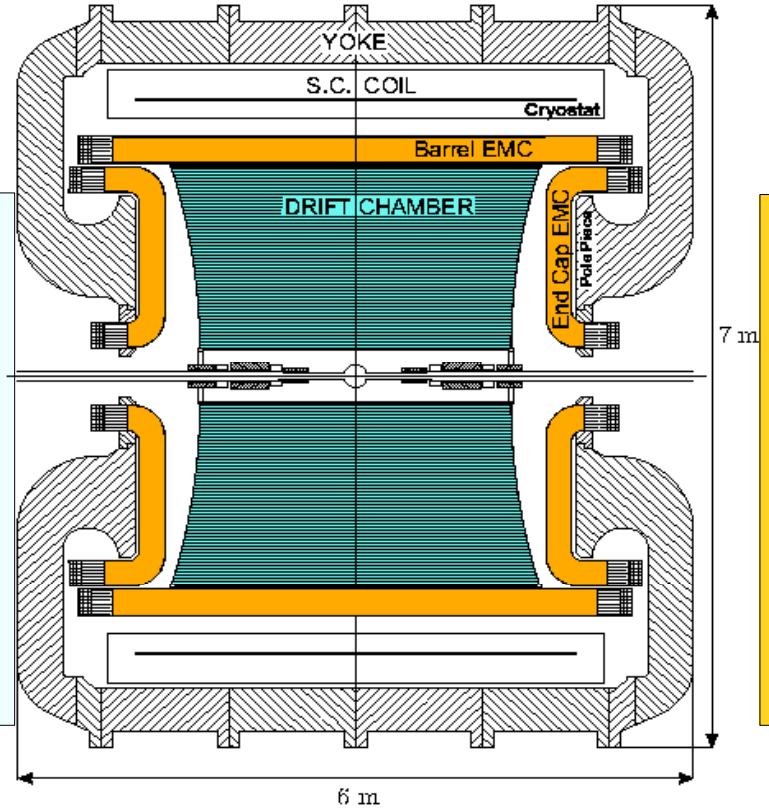
Detector design optimized for K_L measurement:

big volume with good ability for kaon decay vertex reconstruction

high track reconstruction efficiency

very good momentum resolution

very good time resolution



Drift Chamber

58 layers, 52140 wires

90% He 10% C_4H_{10}

$\sigma_{r\phi}$ = 150 μm

σ_z = 2 mm

$\sigma_p/p \sim 4 \times 10^{-3}$

Electromagnetic Calorimeter

Barrel + End caps

Lead-scintillating fibers

98% solid angle coverage

$\sigma_t = 57 \text{ ps} / \sqrt{(E[\text{GeV}])} \oplus 100 \text{ ps}$

$\sigma_E/E = 0.057 / \sqrt{(E[\text{GeV}])}$

η-η′ mixing and η′ gluonic content

KLOE old result

η' considered a good candidate to host gluonium content
In the constituent quark model one can extract gluonium content together with the η-η ′ mixing angle

Rosner PRD 27 (1983) 1101

ϕ_P = η–η' mixing angle

$|\eta'\rangle = X_{\eta'}|q\bar{q}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_G|G\rangle$

$|\eta\rangle = \cos\phi_P|q\bar{q}\rangle - \sin\phi_P|s\bar{s}\rangle$

$X_{\eta'} = \sin\phi_P \cos\phi_G$

$Y_{\eta'} = \cos\phi_P \cos\phi_G$

$Z_G = \sin\phi_G$ gluonium content

KLOE PLB 648 (2007) 267

$$R_\phi = \frac{BR(\phi\to\eta'\gamma)}{BR(\phi\to\eta\gamma)} = (4.77 \pm 0.09_{stat.} \pm 0.19_{syst.}) \times 10^{-3}$$

$\phi_P = (39.7 \pm 0.7)°$

$(Z_G)^2 = 0.14 \pm 0.04$

$P(\chi^2) = 0.49$

Gluonium at 3σ

Imposing Z_G =0 → $P(\chi^2)$ = 0.01

Escribano-Nadal *JHEP* 0705:006, 2007

$(Z_G)^2 = 0.04 \pm 0.09$

Difference attributed to the use in the fit of theoretical parameters $\mathbf{Z_s}$, $\mathbf{Z_q}$, ϕ_V, $\mathbf{m_s/m}$ from Bramon *et al.* PLB 503 (2001) 271 where Z_G =0 is assumed

KLOE new fit

5 more relations added

- $\Gamma(\eta'\to\gamma\gamma)/\Gamma(\pi^0\to\gamma\gamma)$
- $\Gamma(\eta'\to\rho\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\eta'\to\omega\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\omega\to\eta\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\rho\to\eta\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\phi\to\eta\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\phi\to\pi^0\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(K^{*+}\to K^+\gamma)/\Gamma(K^{*0}\to K^0\gamma)$

Parameters

Z_s , Z_q , ϕ_V , m_s/m

are left free

The new result includes the recent KLOE BR measurement

$BR(\omega \to \pi^0\gamma) = (8.09 \pm 0.14)\ \%$ [**PLB 669 (2008) 223**]

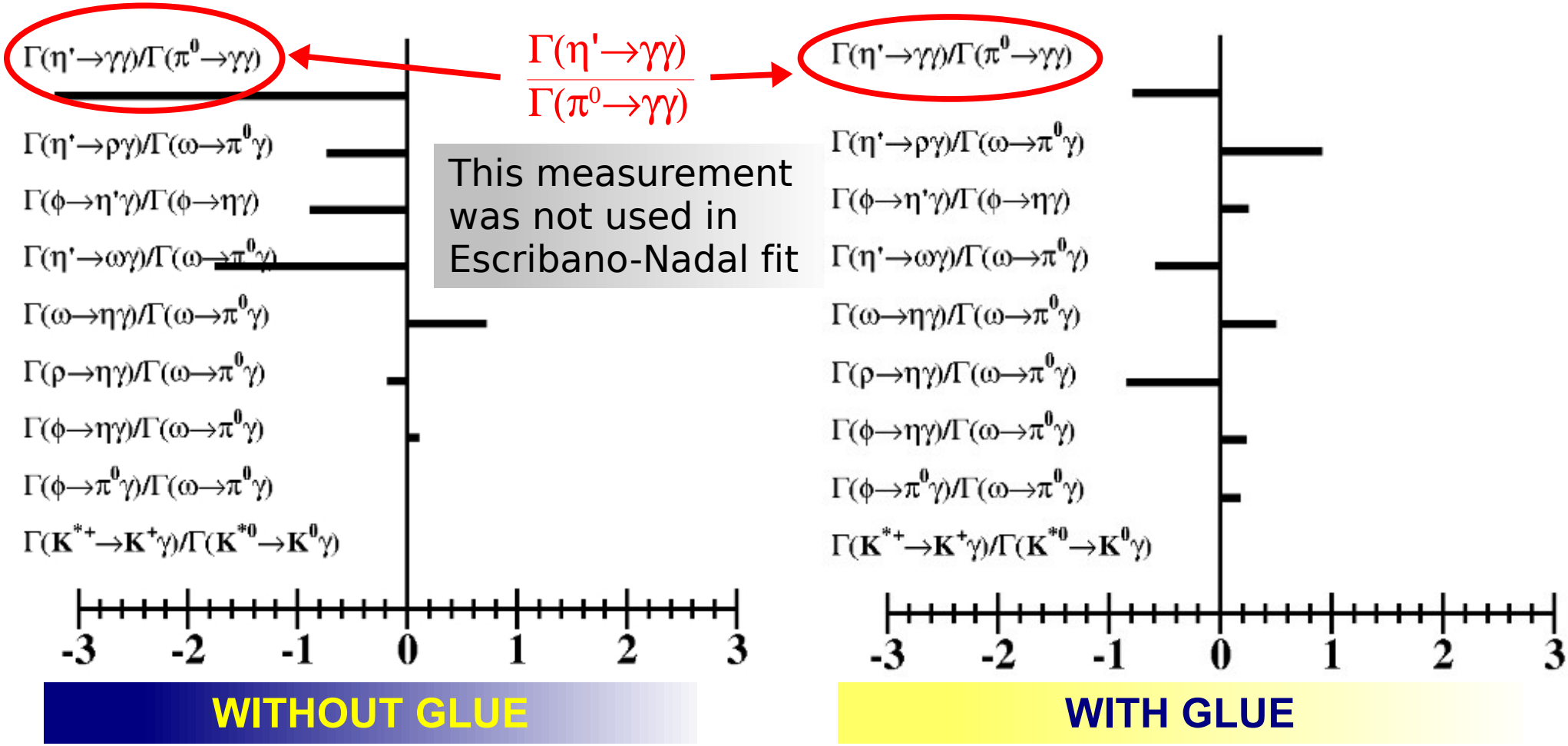
and the lattice results for decay constants ratios assuming exact isospin symmetry.

In addition the fit has been updated with all recent measurements from PDG'08

KLOE new fit

χ^2/dof = 14.7/4	$(Z_G)^2$	fixed 0	0.115 ± 0.036
	ϕ_P	(41.4 ± 0.5)°	(40.4 ± 0.6)°
P(χ^2) = 0.005			χ^2/dof = 4.6/3
			P(χ^2) = 0.20

Pulls = (Meas-Fit)/$\sigma_{Measurement}$



$\frac{\Gamma(\eta'\to\gamma\gamma)}{\Gamma(\pi^0\to\gamma\gamma)}$

This measurement was not used in Escribano-Nadal fit

WITHOUT GLUE **WITH GLUE**

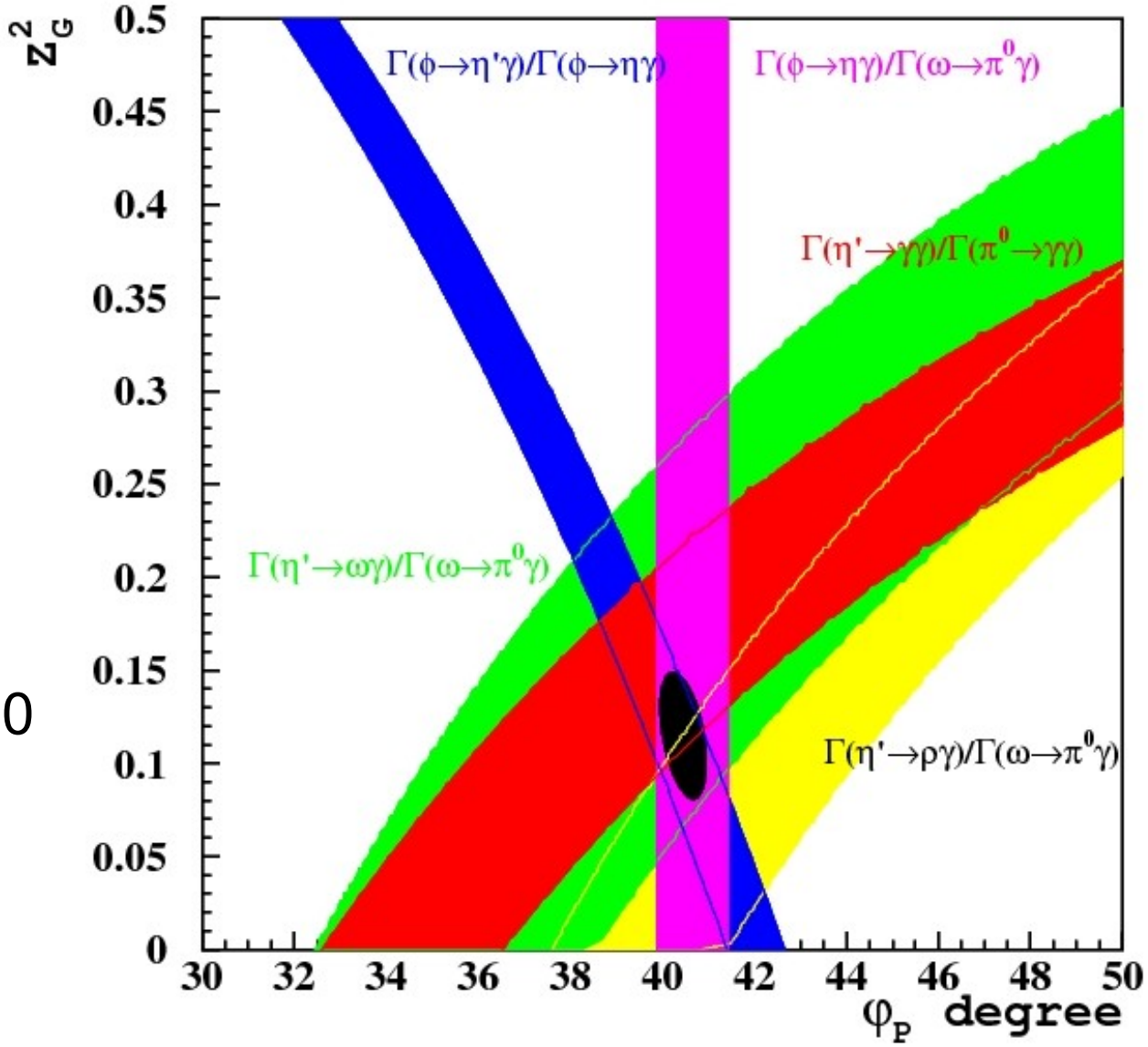
KLOE new fit results

with glue

$(Z_G)^2$	0.115 ± 0.036
ϕ_P	(40.4 ± 0.6)°
Z_q	0.94 ± 0.03
Z_s	0.83 ± 0.05
ϕ_V	(3.32 ± 0.09)°
m_s / m	1.24 ± 0.07

χ^2/dof = 4.6/3 P(χ^2) = 0.20

Using PDG 2008
KLOE results on ω
5 constraints more
gluonium at 3σ confirmed



68% CL contour of the η' related measurements in the Z^2_G - ϕ_P plane

$$\eta \longrightarrow \pi^{+}\pi^{-}e^{+}e^{-}$$

Motivations

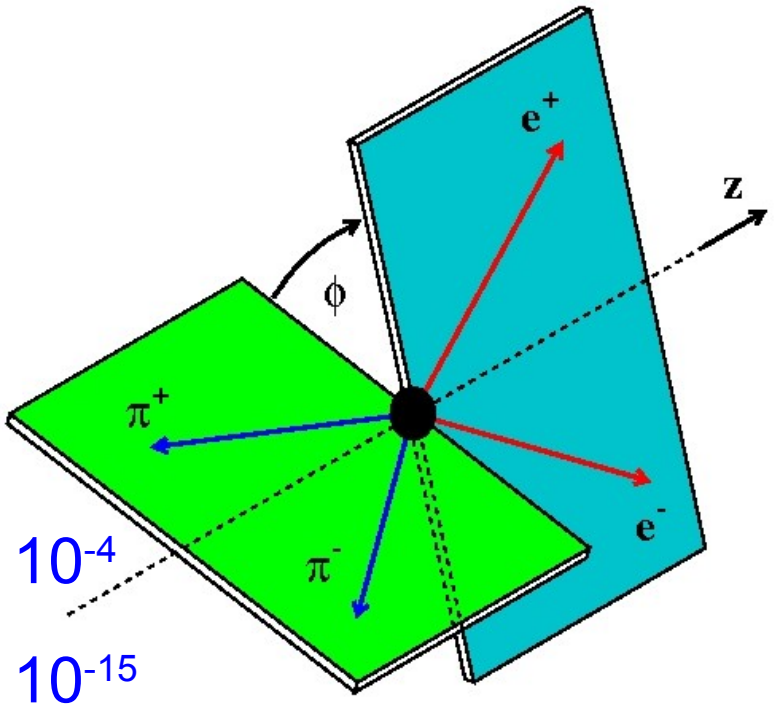
Existing data: 4 events CMD-2, 16 events CELSIUS-WASA

η structure studying virtual photon via M_{ee}

Test of CP violation by measurement of angular asymmetry between e+e- and π+π– planes

Gao, Mod. Phys. Lett. A17(2002) 1583

$$A_\phi = \frac{N_{sin(\phi)cos(\phi)>0} - N_{sin(\phi)cos(\phi)<0}}{N_{sin(\phi)cos(\phi)>0} + N_{sin(\phi)cos(\phi)<0}}$$



Within SM constrained by BR(η→ππ):

using experimental upper limit: $A_\phi < 10^{-4}$

using theoretical prediction: $A_\phi \sim 10^{-15}$

The unconventional CPV term can increase A_ϕ up to 10^{-2}

Analysis scheme

Data sample: 1.7 fb^{-1}

PID using TOF from EM calorimeter

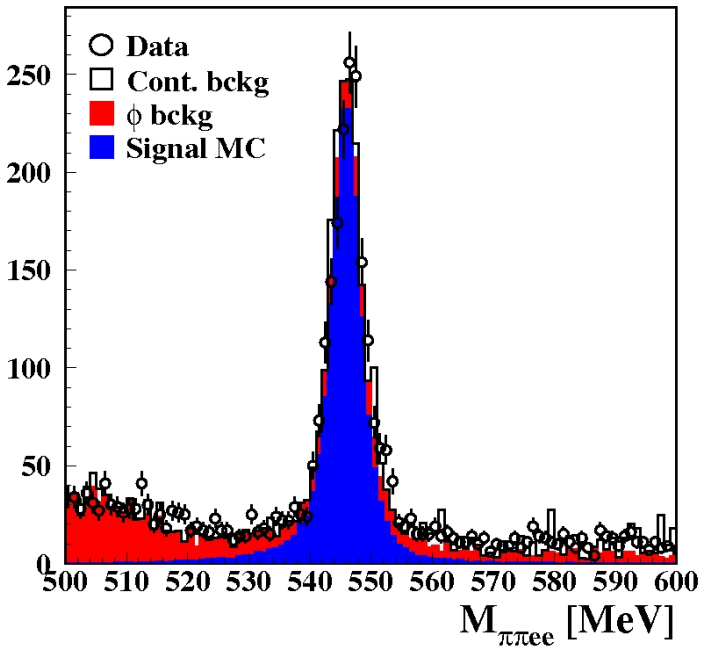
Fit to $M_{\pi\pi ee}$ sidebands for background scale factors

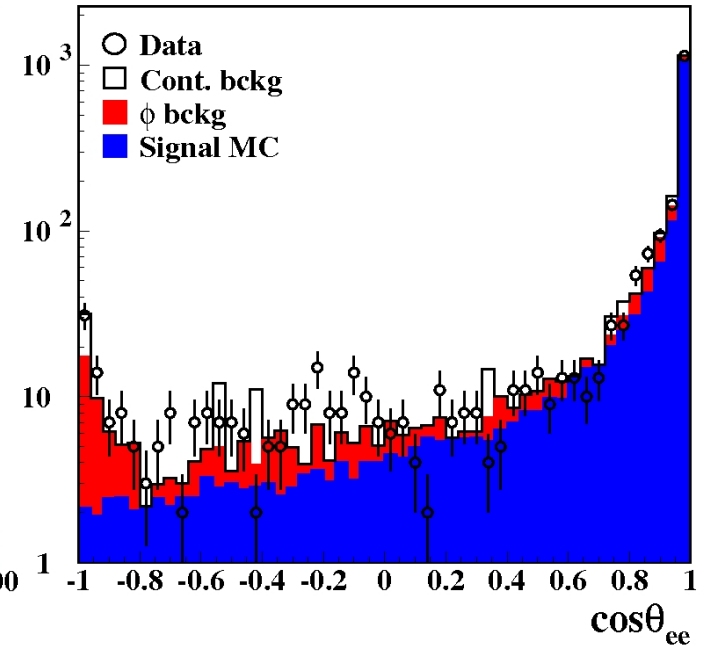
Photon conversion on Beam Pipe rejected

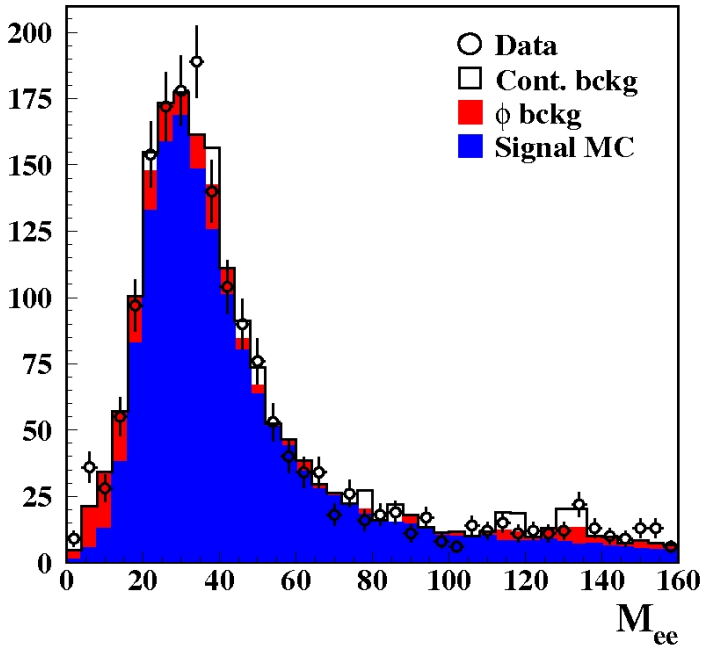
Counting on $M_{\pi\pi ee}$ in the signal region: **$N_{\pi\pi ee}$ = 1555 ± 52**

Analysis efficiency ~8%

368 bkg events







Results: BR and Asymmetry

$$BR(\eta \to \pi^+ \pi^- e^+ e^-) = (26.8 \pm 0.9_{Stat.} \pm 0.7_{Syst.}) \cdot 10^{-5}$$

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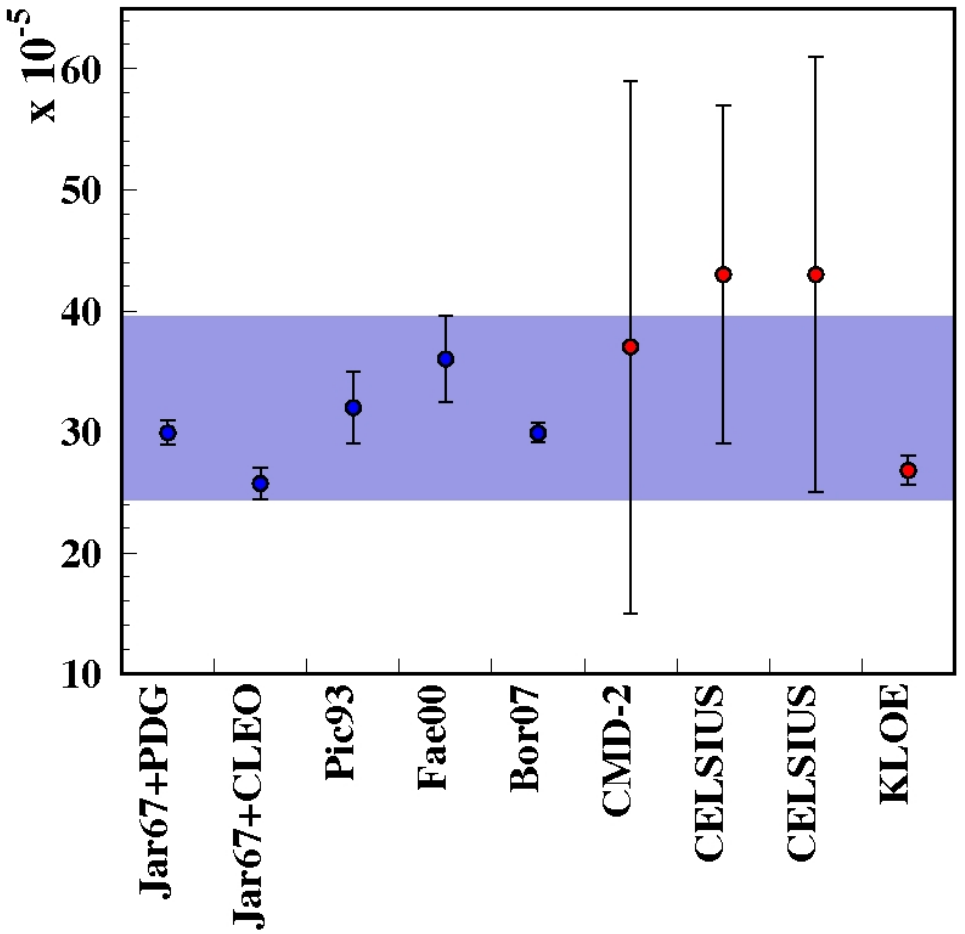
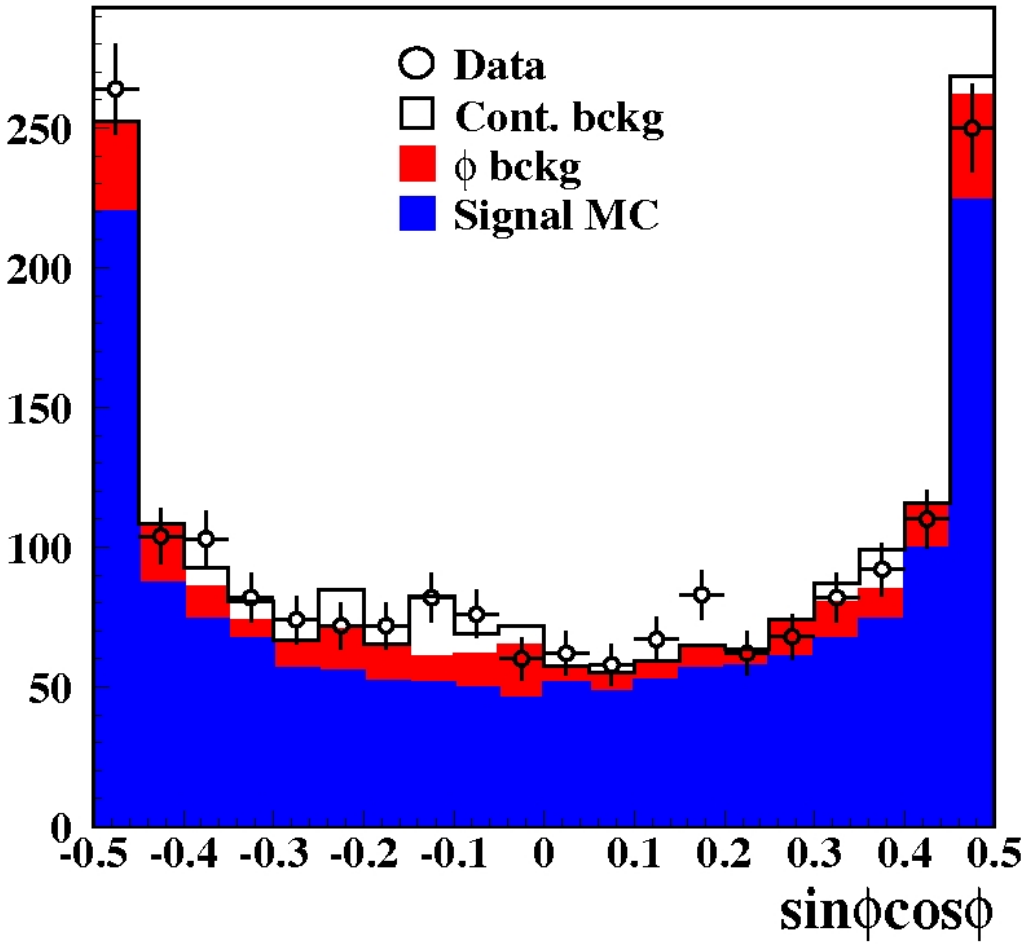
$$A_\phi = (-0.6 \pm 2.5_{Stat.} \pm 1.8_{Syst.}) \cdot 10^{-2}$$

First measurement!





$$\eta \longrightarrow e^{+} e^{-} e^{+} e^{-}$$

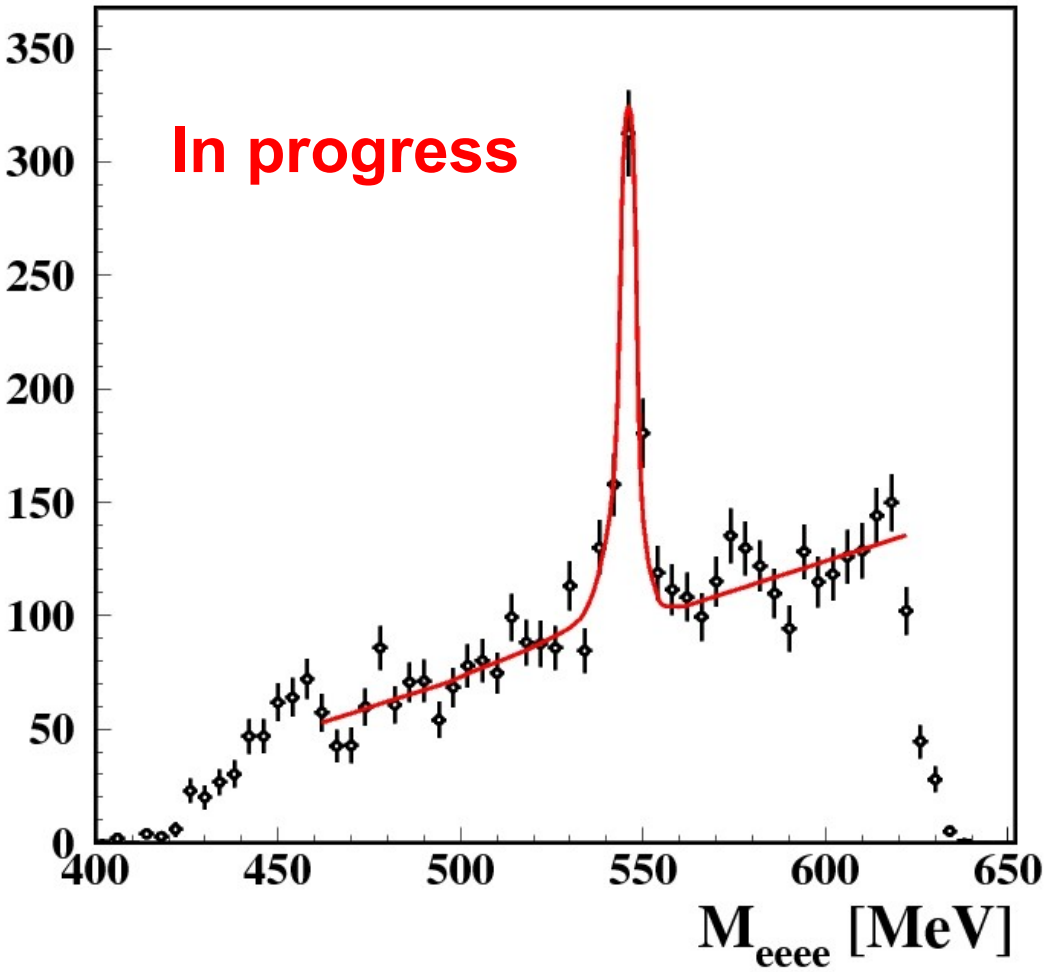
$\eta \to e^+e^-e^+e^-$ analysis

- Data sample: 1.7 fb^{-1}
- e+e- pairs from photon conversion on Beam Pipe and Drift Chamber wall rejected
- Remaining background from ϕ decay is subtracted

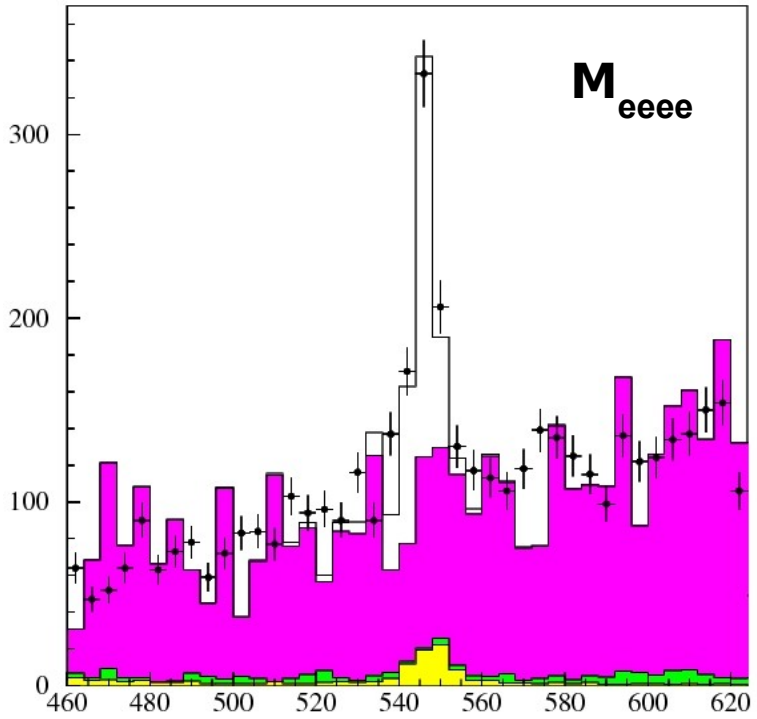
Preliminary fit to M_{eeee} distribution with MC signal + continuum background shapes yields:

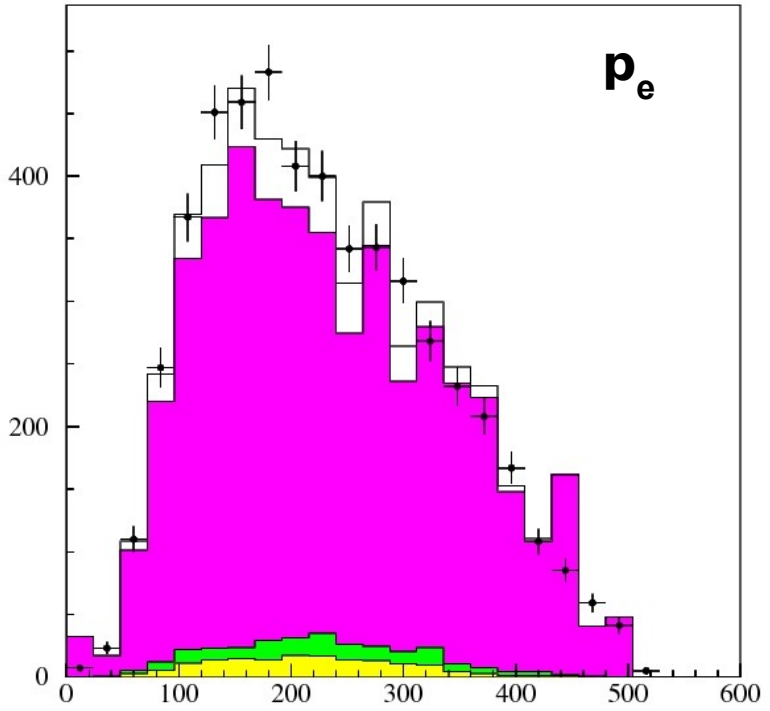
N_{eeee} = 413 ± 31

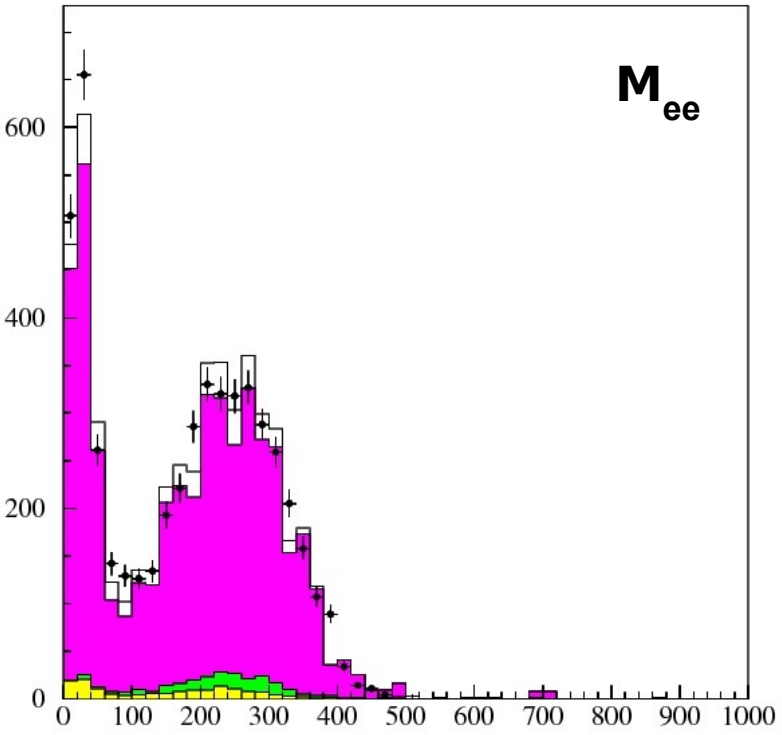
First observation!

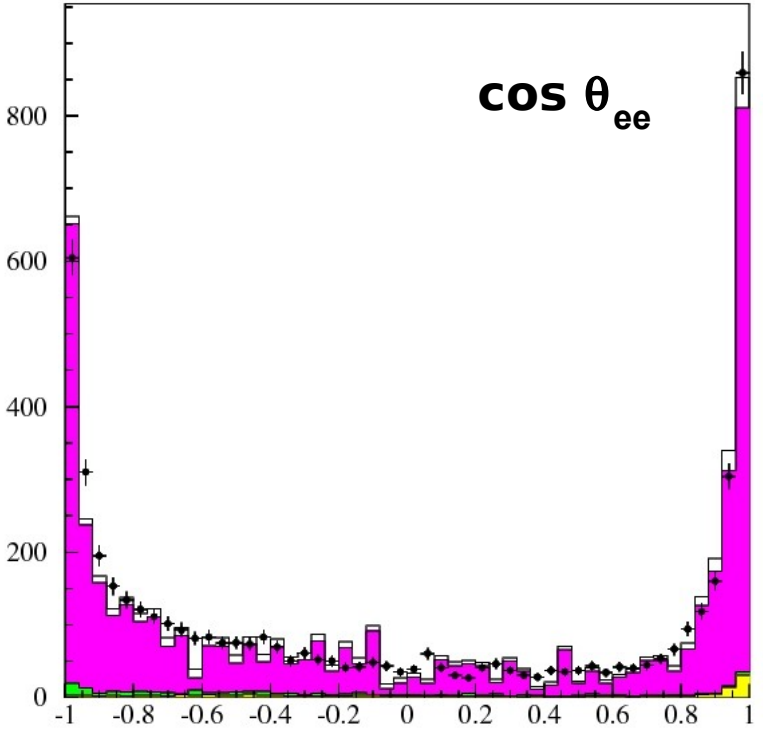


Experiment - MC comparison









Data
MC signal
Cont. bkg
ϕ bkg

$$\eta \rightarrow \pi^{+}\pi^{-}\gamma \quad and \quad \eta \rightarrow \pi^{+}\pi^{-}\pi^{0}$$

Motivations

The Box Anomaly

In the $\eta \to \pi^+\pi^-\gamma$ decay a significant contribution from the chiral anomaly responsible for $\eta \to \gamma\gamma$ decay is expected

Studies of the two pion system allow for tests of ChPT and its unitarized extensions, e.g. VMD or the chiral unitary approach.

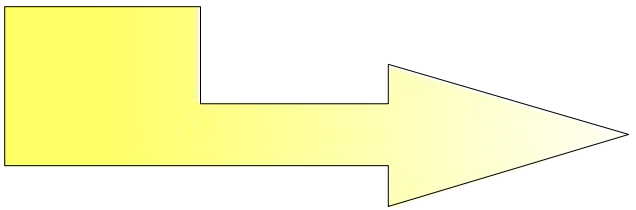
Holstein, Phys. Scripta, T99 55 (2002)
Benayoun, Eur. Phys. J., C31 525 (2003)
Borasoy, Nissler, Nucl. Phys., A740 362 (2004)

Existing data

Low in statistic and not acceptance corrected
Not sufficient for unambiguous theoretical interpretation

Gormley, Phys.Rev. D2 501 (1970)
Layter, Phys.Rev. D7 2565 (1973)

Latest results from CLEO on the ratio of charged decays BRs differ > 3σ from old results



$\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$

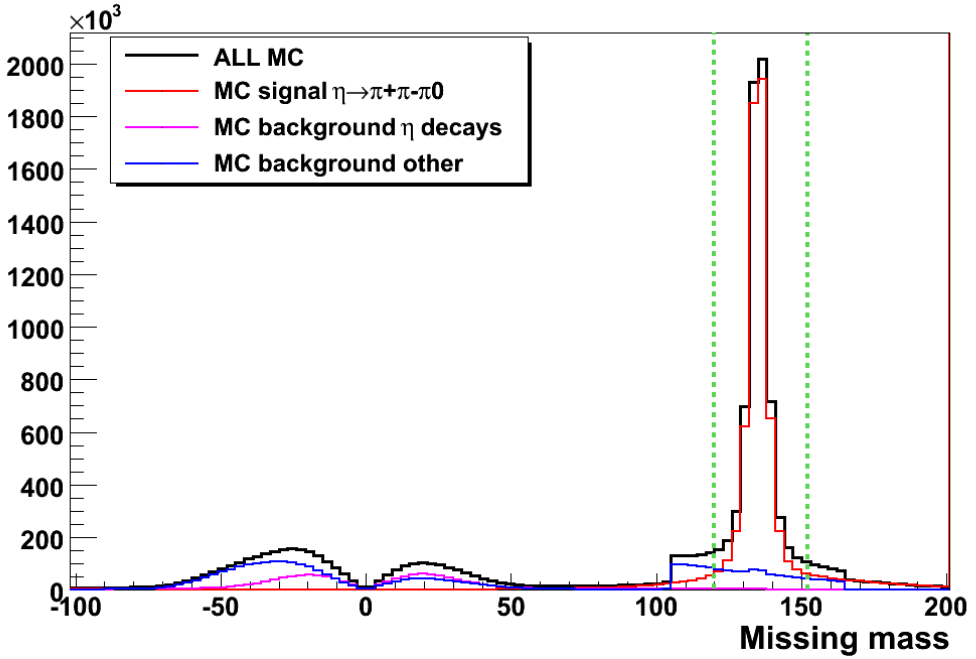
VALUE	EVTS	DOCUMENT ID		TECN
0.202±0.007 OUR FIT	Error includes scale factor of 2.4.			
0.203±0.008 OUR AVERAGE	Error includes scale factor of 2.4.			
0.175±0.007±0.006	859	LOPEZ	07	CLEO
0.209±0.004	18k	THALER	73	ASPK
0.201±0.006	7250	GORMLEY	70	ASPK

Selection: $\eta \rightarrow \pi^+\pi^-\pi^0$ and $\eta \rightarrow \pi^+\pi^-\gamma$

No kinematical fit, signal selection with help of kinematical constraints from consecutive decays i.e.

$\phi \rightarrow \eta\gamma, \quad \eta \rightarrow \pi^+\pi^-\pi^0, \quad \pi^0 \rightarrow \gamma\gamma$

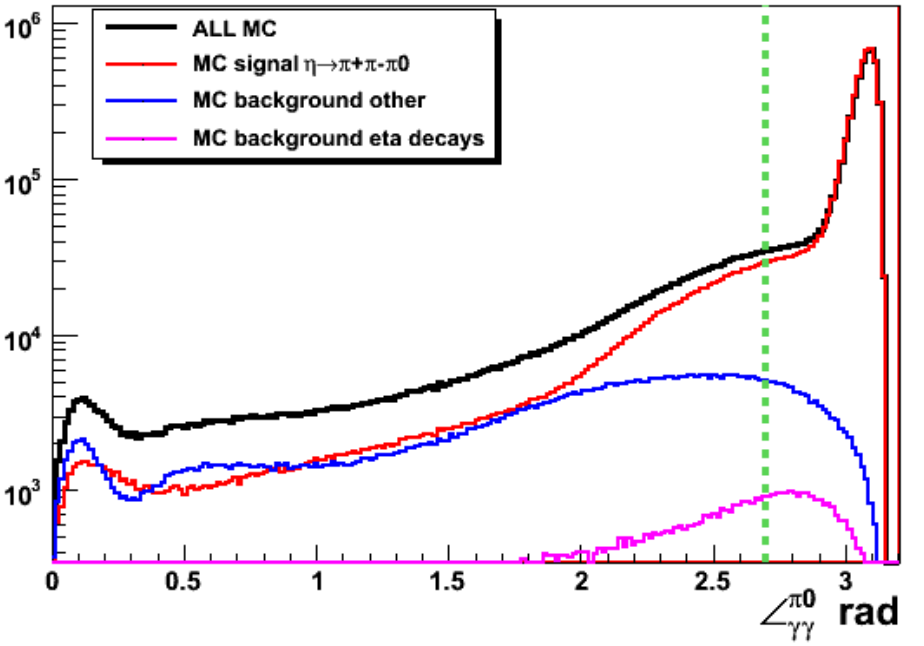
$\phi \rightarrow \eta\gamma, \quad \eta \rightarrow \pi^+\pi^-\gamma$



For $\eta \rightarrow \pi^+\pi^-\pi^0$:

- Missing mass to ($\phi - \pi^+ - \pi^- - \gamma_\phi$) system
- Opening angle ($\gamma_\eta^{\,1}\ \gamma_\eta^{\,2}$) in the π^0 rest frame

Eff = 40 % with BKG/SIG = 0.5 %



Selection: $\eta \rightarrow \pi^+\pi^-\pi^0$ and $\eta \rightarrow \pi^+\pi^-\gamma$

For $\eta \rightarrow \pi^+\pi^-\gamma$:

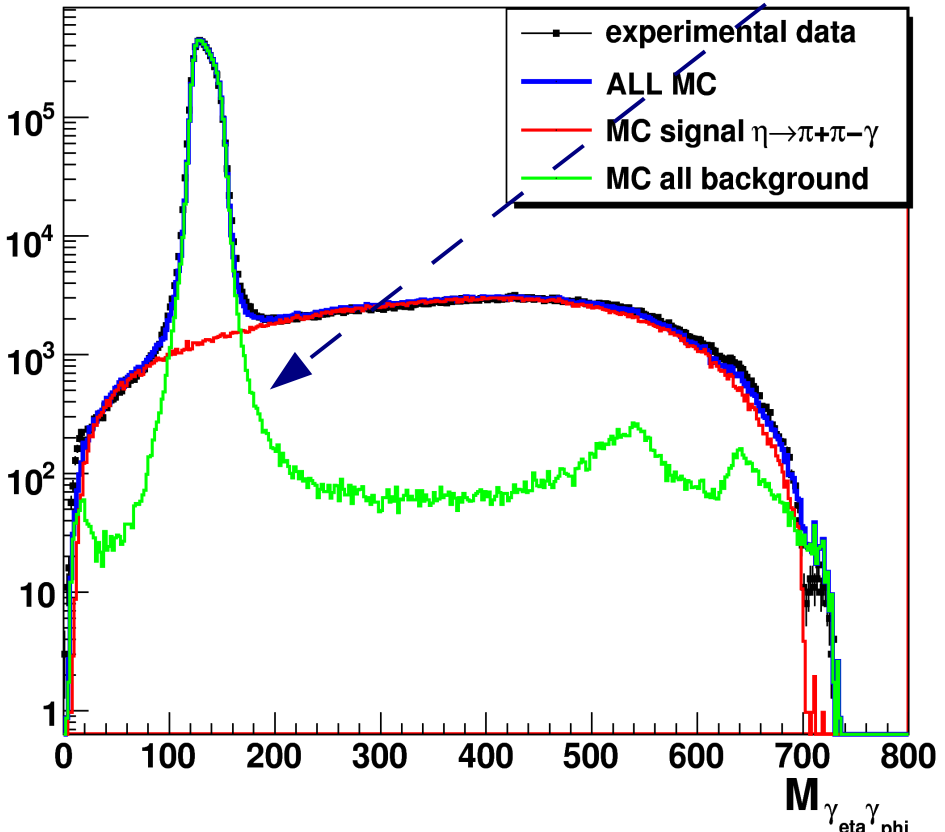
- Similar cuts ($(E_\gamma - P_\gamma)$ instead of missing mass, angle selection)

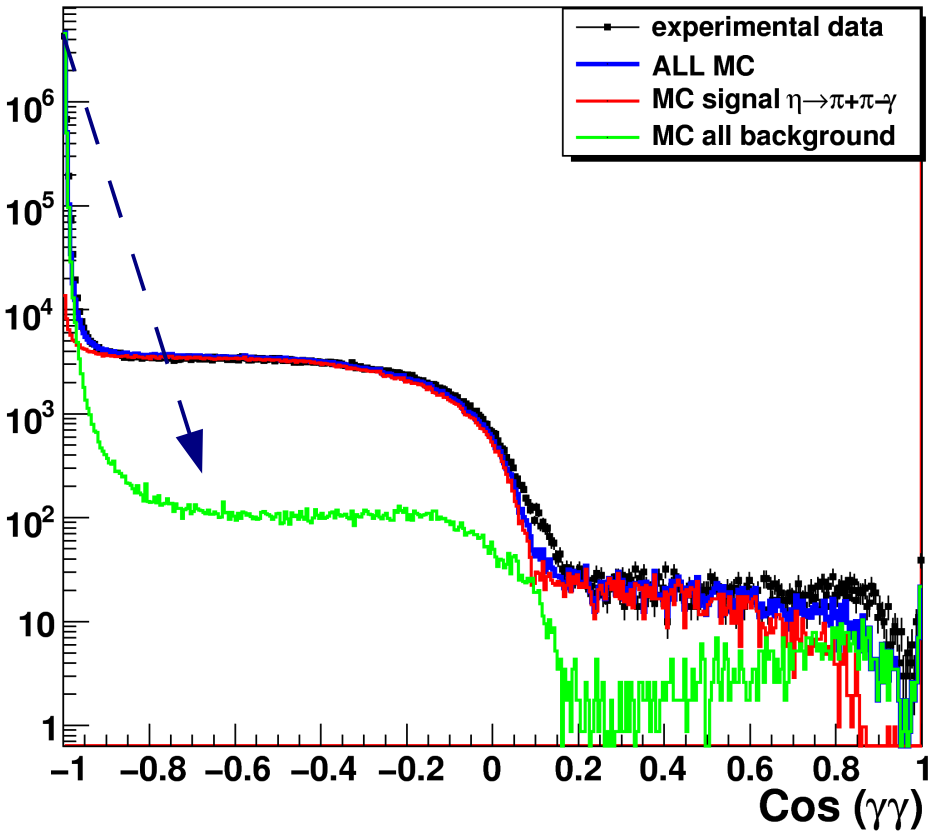
Eff = 29 % , BKG/SIG = 10:1

surviving background $\phi \rightarrow \pi^+\pi^-\pi^0$

different topology in $\gamma\gamma$ distributions

simultaneous fit to both spectra





PRELIMINARY RESULTS:

$\Gamma(\eta\to\pi^+\pi^-\gamma) / \Gamma(\eta\to\pi^+\pi^-\pi^0)$

(based on 1.2 fb^{-1} data set)

$$\frac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)} = 0.2014 \pm 0.0004_{\text{stat}}$$

OUTLOOK

- Our preliminary results agrees with PDG values, confirming old results from '70s.
- We are evaluating systematics, aiming at value < 1%
- Cuts on $M_{\gamma\gamma}$ and $\cos(\gamma_\phi \gamma_\eta)$ in the π^0 rest frame will allow for significant background reduction
- Plan to use full KLOE data set (*statistical precision ~0.15%*) and investigate in detail the $\pi^+\pi^-$ invariant mass distribution and photon energy spectrum in order to disentangle non-resonant contributions and settle the inconsistencies of previous measurements.

SUMMARY

- Gluonium content confirmed at 3σ level in η′ using the Rosner model (paper submitted to JHEP (ArXiv 0906.3819))
- BR and the first measurement of asymmetry in $\eta \to \pi^+ \pi^- e^+ e^-$ decay:

  $BR = (26.8 \pm 0.9_{Stat.} \pm 0.7_{Syst.}) \cdot 10^{-5}$

  $A_\phi = (-0.6 \pm 2.5_{Stat.} \pm 1.8_{Syst.}) \cdot 10^{-2}$
- First observation of the $\eta \to e^+e^-e^+e^-$ decay ~400 events
- New analysis has been started on $\eta \to \pi^+\pi^-\gamma$. Preliminary results on the ratio of BRs: $\frac{\Gamma(\eta \to \pi+\pi-\gamma)}{\Gamma(\eta \to \pi+\pi-\pi 0)} = 0.2014 \pm 0.0004(stat)$
- Other analysis in progress:

  $\eta \to \pi^0\gamma\gamma$, $\eta \to \mu^+\mu^-$, $\eta' \to \pi^+\pi^-\eta$, $\eta' \to \pi^+\pi^-\gamma$.

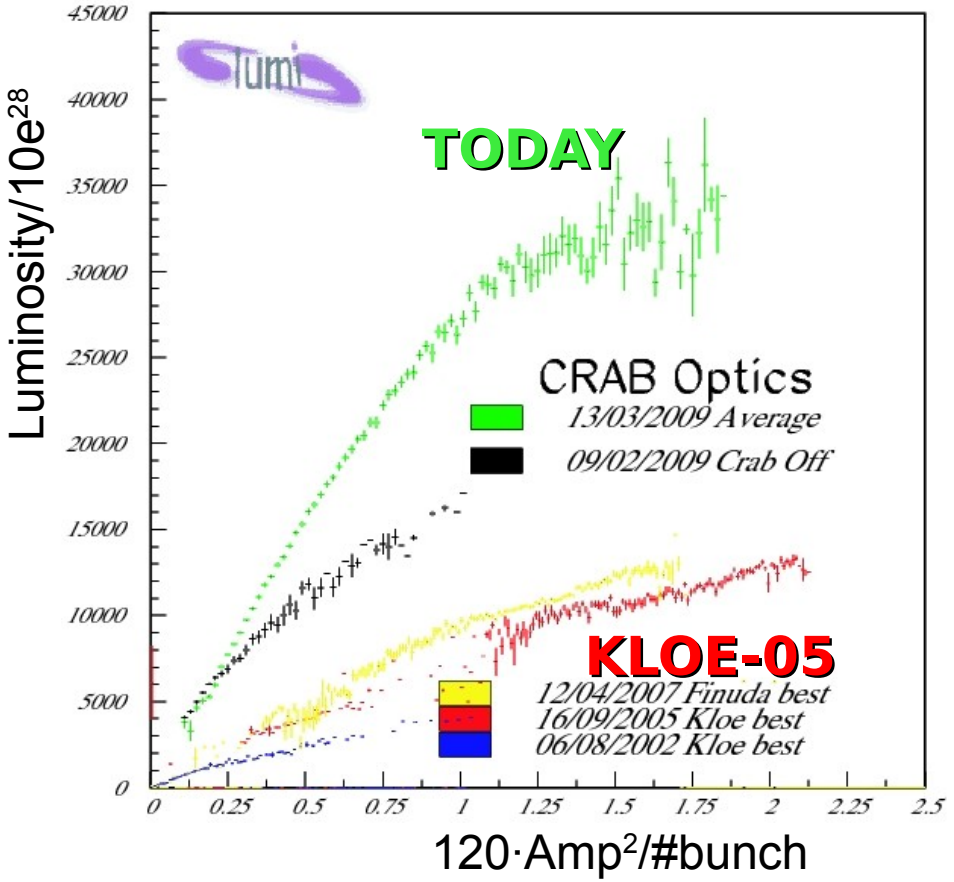
DAΦNE and KLOE upgrades

New machine magnetic scheme:

crab waist

$L_{peak} = 5\times10^{32}\ cm^{-2}s^{-1}$

$\int L = 15\ pb^{-1}/day$



STEP-0 [2009]: **5fb^{-1}**

$\gamma\gamma$ tagger

STEP-1 [2011]: **>20fb^{-1}**

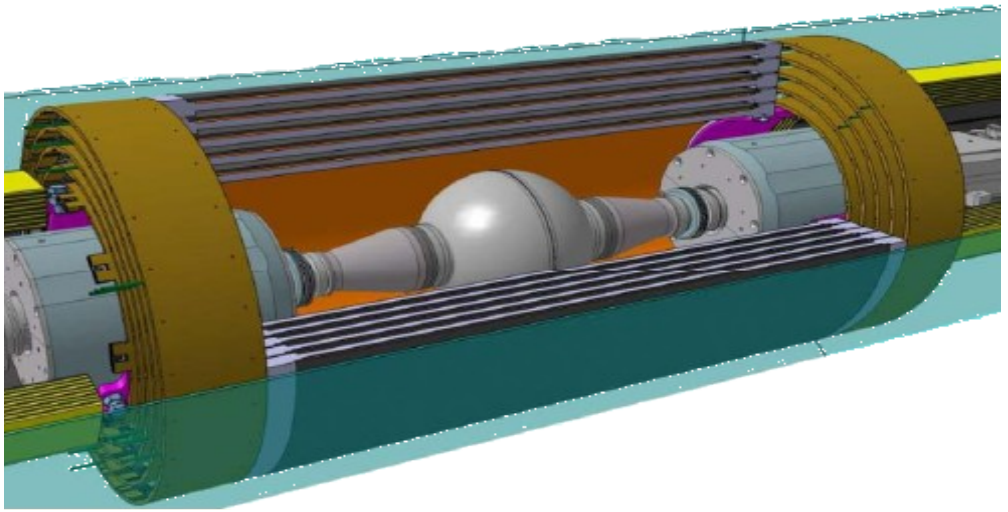
Low Angle Calorimeter

Quadrupole Calorimeter

Inner Tracker

New interaction region:

larger crossing angle



KLOE-2 perspectives on eta/eta' physics examples:

Refinement of rare η decay measurements

Improve result on $\eta \to \pi^+\pi^- e^+ e^-$ BR and CPV asymmetry

Form factor studies

Decays $\eta \to ee\gamma$, $\eta \to \mu\mu\gamma$, $\eta \to eeee$

Comparison between $\eta \to \pi\pi ee$, $\eta \to eeee$, $\eta \to \mu\mu ee$ channels

Test of theoretical calculation

High statistics study of the process $\eta \to \pi^0\gamma\gamma$ would allow to strongly test ChPT $O(p^6)$ calculations

Open a window on η' physics

Measurement of the all main η' BR's together with η' decay width $\sigma(e^+e^- \to e^+e^- \gamma^*\gamma^* \to e^+e^- \eta')$ at 1% precision would be necessary to solve the gluonium puzzle

SPARES

KLOE old result

2001-2002 data: 427 pb^{-1}

$$R_\phi = \frac{BR(\phi\to\eta'\gamma)}{BR(\phi\to\eta\gamma)} = (4.77 \pm 0.09_{stat.} \pm 0.19_{syst.}) \times 10^{-3}$$

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Experimental inputs:

- R_ϕ
- $\Gamma(\eta'\to\gamma\gamma)/\Gamma(\pi^0\to\gamma\gamma)$
- $\Gamma(\eta'\to\rho\gamma)/\Gamma(\omega\to\pi^0\gamma)$
- $\Gamma(\eta'\to\omega\gamma)/\Gamma(\omega\to\pi^0\gamma)$

$\phi_P = (39.7 \pm 0.7)°$

$(Z_G)^2 = 0.14 \pm 0.04$

$P(\chi^2) = 0.49$

Theoretical parameters

Z_s , Z_q , ϕ_V , m_s/m

taken from

Bramon *et al.* PLB 503(2001) 271

where $Z_G = 0$ is assumed

$$Z_q = \langle\eta_q|\omega_q\rangle/\langle\pi|\omega_q\rangle = \langle\eta_q|\rho\rangle/\langle\pi|\rho\rangle$$

$$Z_s = \langle\eta_s|\phi_s\rangle/\langle\pi|\rho\rangle$$

ϕ_V is ϕ-ω mixing angle

KLOE *Phys. Lett.* B648 (2007) 267

$\phi_P = (39.7 \pm 0.7)^o$

$|\phi_G| = (22 \pm 3)^o$

$\sin^2\phi_G = (Z_G)^2 = 0.14 \pm 0.04$

Only ϕ_P and Z_G are free

Γ's used in the fit

4 measured quantities <u>including</u>

$\eta' \to \gamma\gamma$ / $\pi^0 \to \gamma\gamma$

Data from

PDG'06 and KLOE R_ϕ '07

Escribano-Nadal *JHEP* 0705:006, 2007

$\phi_P = (41.4 \pm 1.3)^o$

$|\phi_G| = (12 \pm 13)^o$

$\sin^2\phi_G = (Z_G)^2 = 0.04 \pm 0.09$

All theoretical parameters are free

Couplings used in the fit

12 measured quantities <u>without</u>

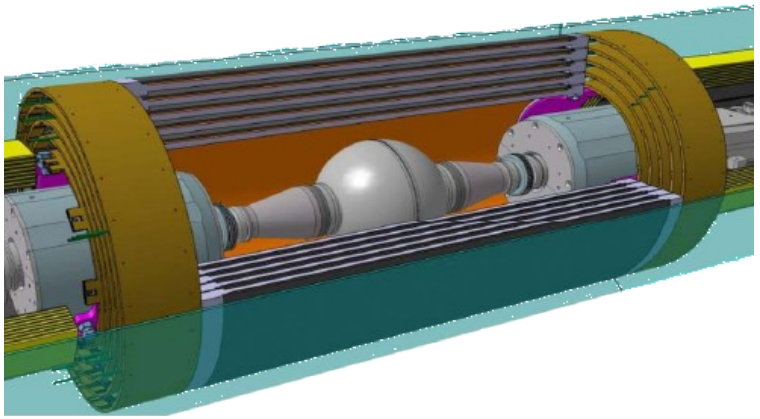
$\eta' \to \gamma\gamma$ / $\pi^0 \to \gamma\gamma$

Data from

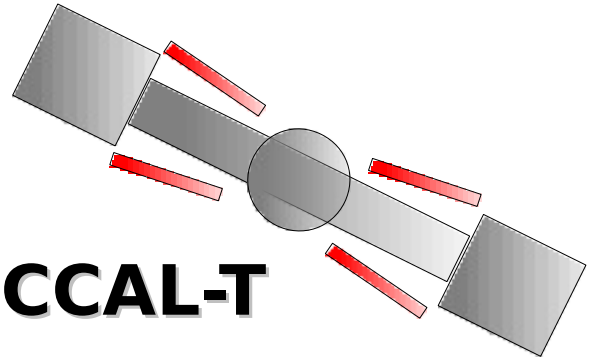
PDG'06

KLOE-2 detector upgrades

Inner Tracker



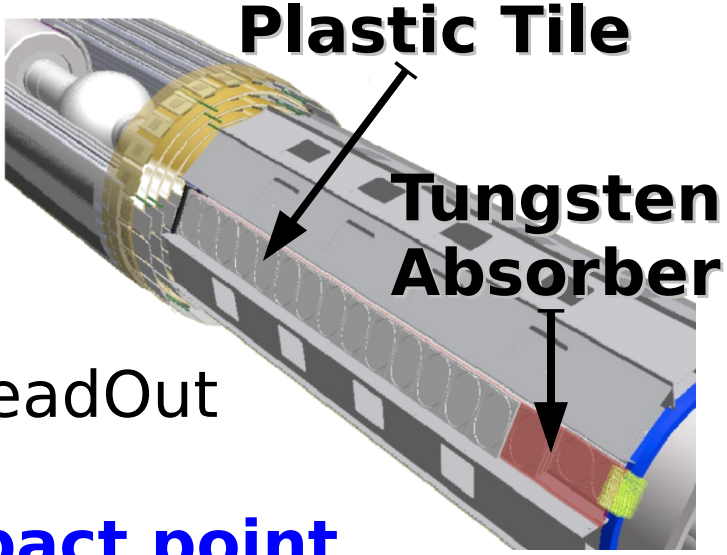
5 GEM planes
Min radius: 13 cm
Max radius: 25 cm
$\sigma_{xy} \sim 200\mu m$ $\sigma_z \sim 500\ \mu m$
Material budget: **0.2 X_0**
Vertex resolution @IP: x3



CCAL-T

LYSO Cristal
Pointing geometry
LOW θ acceptance

QCAL-T

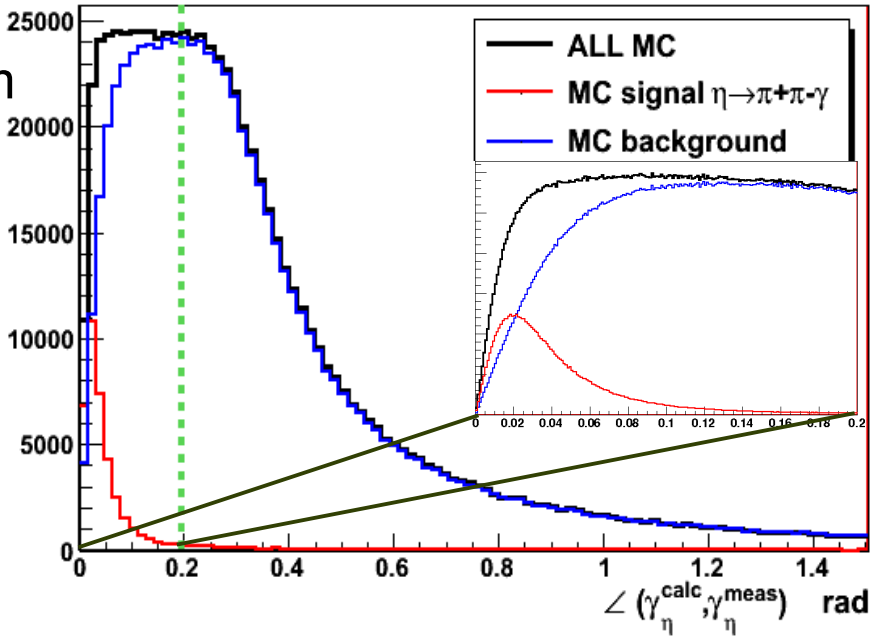


1m cylinder
12 segment
Single tile ReadOut
with fiber
Photon impact point resolution increase: x10

Selection: $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to \pi^+\pi^-\gamma$

For $\eta \to \pi^+\pi^-\gamma$:

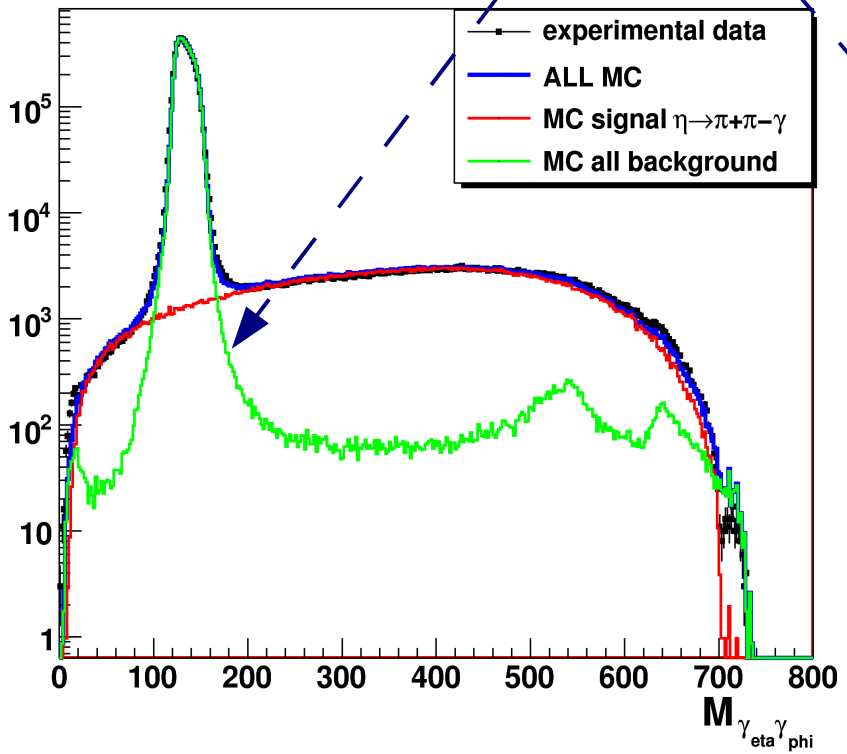
- $(E_\gamma - P_\gamma)$ of γ_η^{calc} from $(\phi - \pi^+ - \pi^- - \gamma_\phi)$ system *(expecting 0 for signal events)*
- Opening angle $(\gamma_\eta^{calc}\,\gamma_\eta^{meas})$

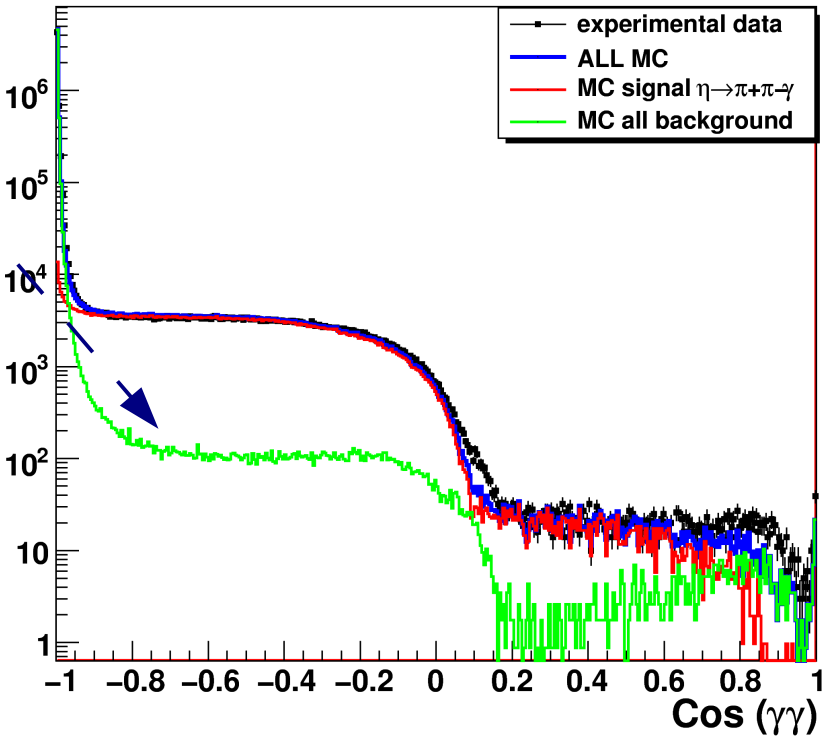


Eff = 29 % , BKG/SIG = 10:1

surviving background $\phi \to \pi^+\pi^-\pi^0$ most pronounced on $\gamma\gamma$ distributions

simultaneous fit to both spectra





1. **EVCL** ≥ 4 tracks and 1 high energy prompt neutral cluster

2. **Momenta** 450 < s4p < 600 MeV `.and.` 270 < s2p < 460 MeV

3. χ^2_{KF} $\chi^2_{KF} < 4000$

At this level we perform the fit to get the scale factors

A kinematic fit to the ϕ meson is performed for
all the events having # good tracks ≥ 4

The 22 inputs are:

- 4 tracks x 3 momenta
- x,y,z,E,t of the neutral cluster
- x,y,z of the IP
- $\sqrt{s}$ and f momentum

The 5 constraints are:

- Four momentum conservation
- Photon time of flight ($cT_\gamma = R_\gamma$)

Physics Motivations

Gormley et al. Phys. Rev. D2 (1970) 501

$$|M|^2 \approx k^2 \sin^2\theta \left(\frac{m_{\pi\pi}}{q}\right) \frac{\Gamma}{\left(m_\rho^2 - m_{\pi\pi}^2\right)^2 + m_\rho^2 \Gamma^2}; \Gamma = \left(q/q_0\right)^3 \gamma$$

Angular distribution expected $\frac{dN}{d(\cos\theta)} = n \sin^2\theta$

QCD Anomaly $\eta / \eta' \to \pi^+ \pi^- \gamma$ unitary effects via final state interactions:

- WZW in the context of HLS
- Chiral unitarity approach Bethe-Salpeter-equation
- Omnes function

Past Results: $\eta \to \pi^+ \pi^- \gamma$

1970-BNL: Gormley et. Al Phys. Rev. D2, 501 (1970)

7250 events spectra agree with simple ρ -dominant model

1973: Layter et. al Phys. Rev. D7, 2565 (1973)

18150 events spectra agree with ρ -dominance of the $\pi^+ \pi^-$ final state