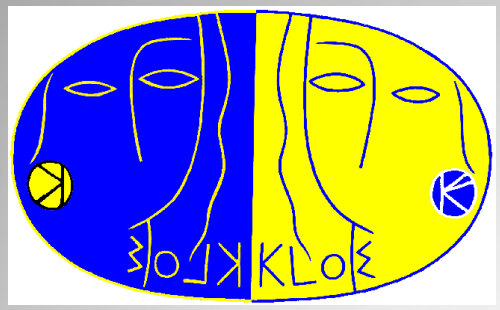


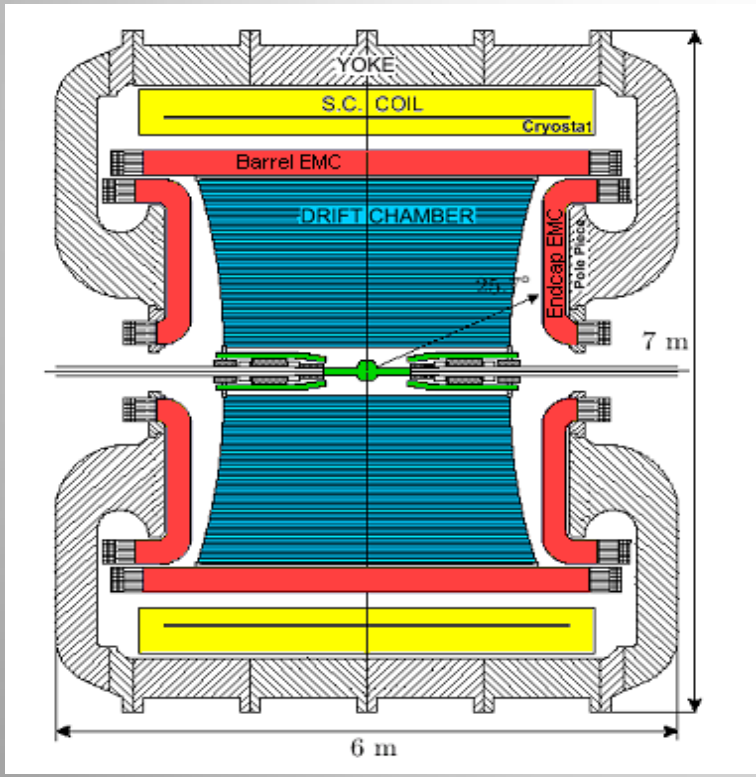
Recent results and perspectives from KLOE/KLOE-2

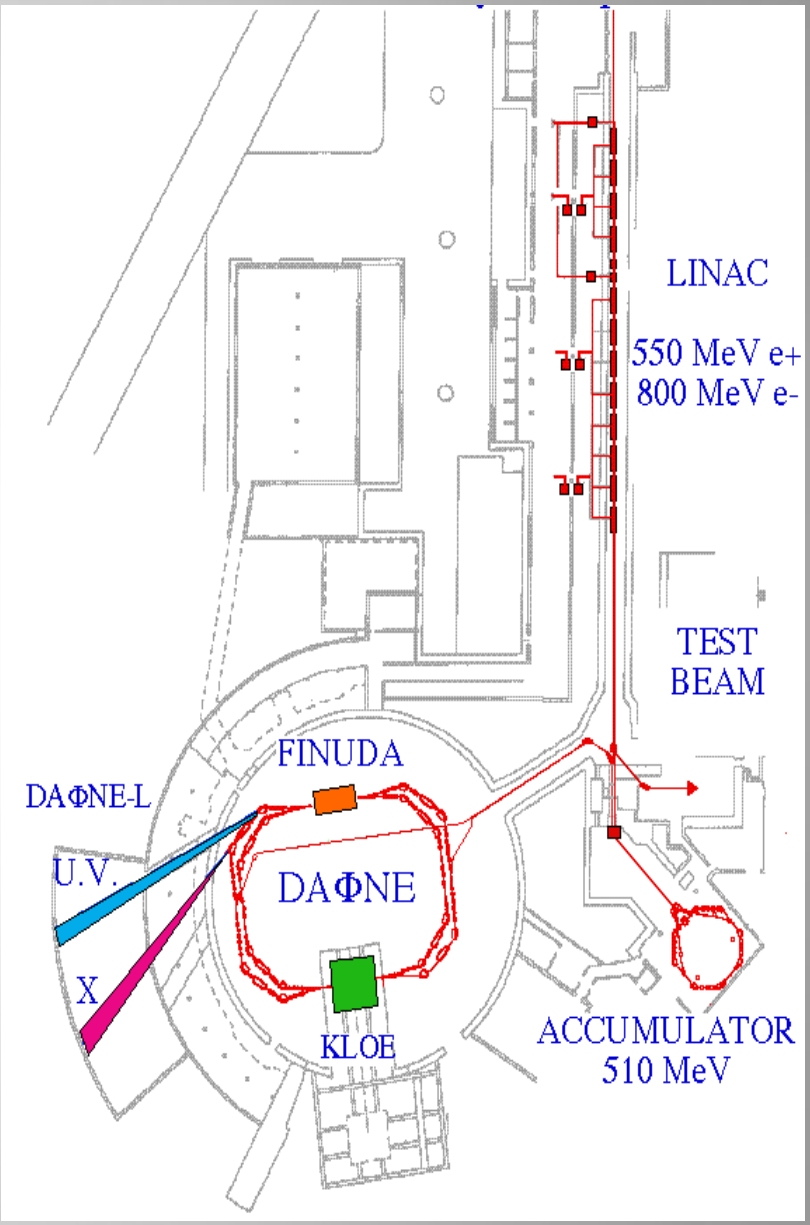
Fabio Bossi, INFN Frascati

Chiral Dynamics 2012

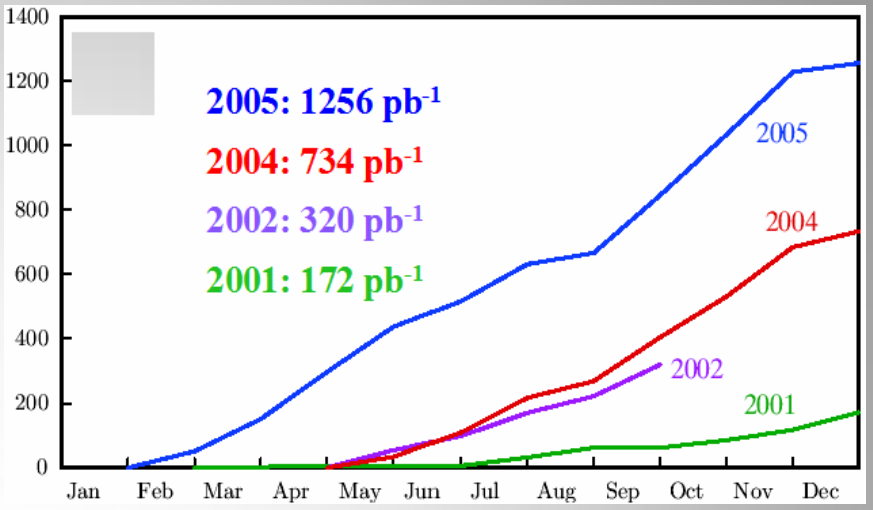
Newport News, Aug 7th 2012

The KLOE detector installed on the Frascati e^+e^- collider DAΦNE, running at the Φ(1020) peak





The experiment has taken data from 2000 to 2006, collecting 2.5 fb^{-1} at the Φ peak, plus additional 0.25 fb^{-1} at 1000 MeV



Using the above data set KLOE has produced in the last decade several physics results, mostly in the fields of:

- Flavour physics ($K_{L,S}$, $K^{\pm}$ decays)
- Hadron physics (light scalar and pseudoscalar meson decays)
- Discrete symmetries (P, C, CP, CPT) conservation
- Tests of quantum mechanics

This “old” data set is still producing new amazing results, some of which I will discuss in the following

In the meanwhile, since a few years, we are preparing a new run on a (potentially) upgraded machine with an upgraded detector

This new project, KLOE-2, aims at collecting a data set larger by ~ an order of magnitude wrt the previous campaign. I will report on its status and perspectives

Running at the Φ peak has several advantages which are well illustrated by all of the channels I will discuss in the following

- Trivially, one can study rare or semi-rare Φ decays, as in the case $\Phi \rightarrow \eta e^+ e^-$
- Charged and neutral kaons are produced at a rate of 1.5 and 1 million pairs per pb^{-1}. In particular one has the unique feauture of a copious well tagged almost background free K_S beam, as in $K_S \rightarrow 3\pi^0$
- Also η mesons are well tagged by the monochromatic 350 MeV photon emitted in the radiative Φ decay. About $4x10^4$ η's are produced per pb^{-1} . Today I will discuss $\eta \rightarrow \pi^+ \pi^- \gamma$

$\Phi \rightarrow \eta e^+e^-$

Although vector meson dominance (VMD) is able to describe well many electromagnetic interactions of hadrons, it however fails in describing all of them. For instance $\omega \rightarrow \pi^0$ transitions are poorly described by VMD

Dalitz decays of the Φ into an η or a π^0 might be very helpful to clarify the matter and test alternatives to VMD

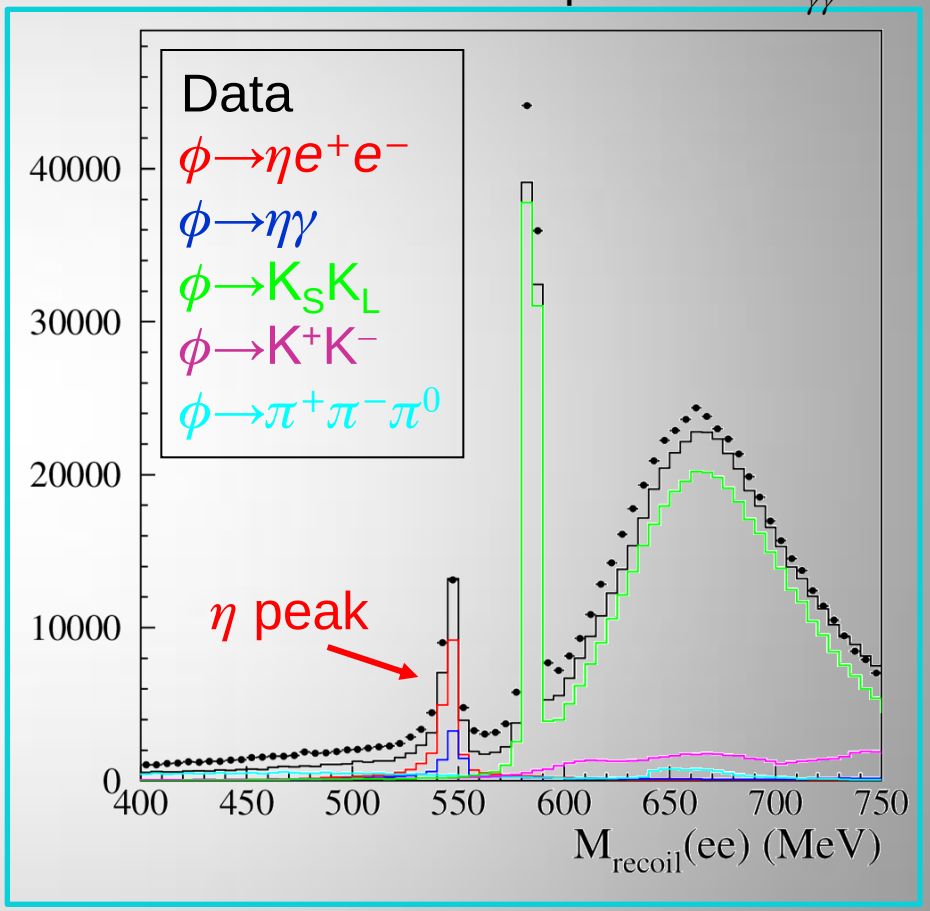
Moreover they turn out to be relevant also to the search for new light non-standard vector bosons (*U* or *A'* bosons)

We have studied $\Phi \rightarrow \eta e^+e^-$ transitions tagging the η by both the $\pi^+\pi^-\pi^0$ and the $3\pi^0$ decay channels

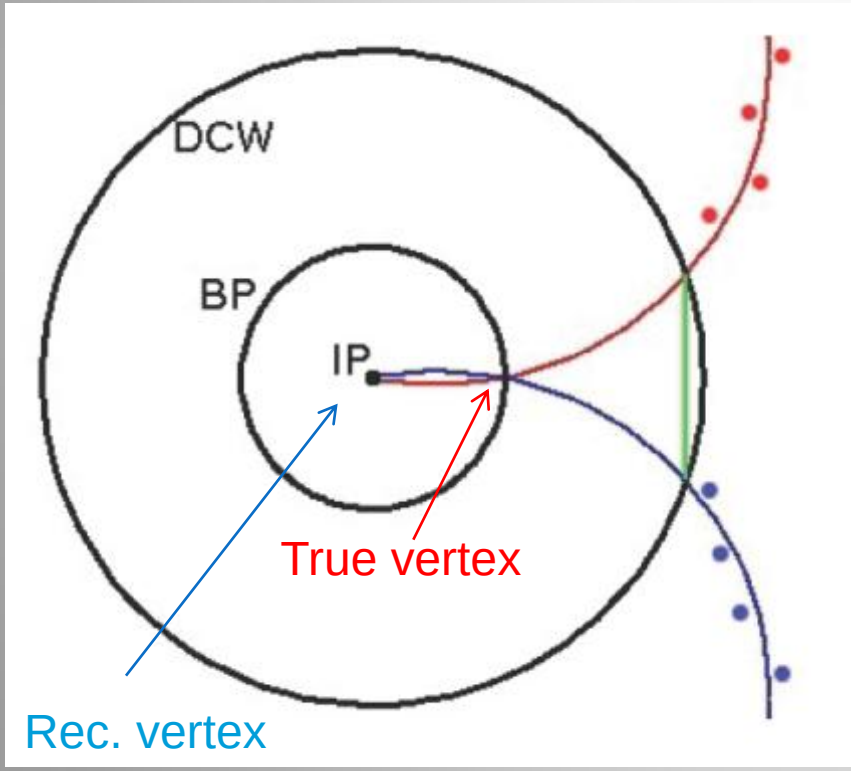
$\Phi \rightarrow \eta e^+e^- \rightarrow \pi^+\pi^-\pi^0 e^+e^-$

- 4 tracks and 2 prompt γ's candidates
- Best $\pi^+\pi^-\gamma\gamma$ match to the η mass using pion hypothesis for tracks. Other two tracks assigned to e^+e^-
- $495 < M_{\pi\pi\gamma\gamma} < 600$ MeV
  $70 < M_{\gamma\gamma} < 200$ MeV
  $535 < M_{recoil} < 560$ MeV
- Photon conversion + ToF cuts

Recoil mass to the e^+e^- pair after $M_{\gamma\gamma}$ cut



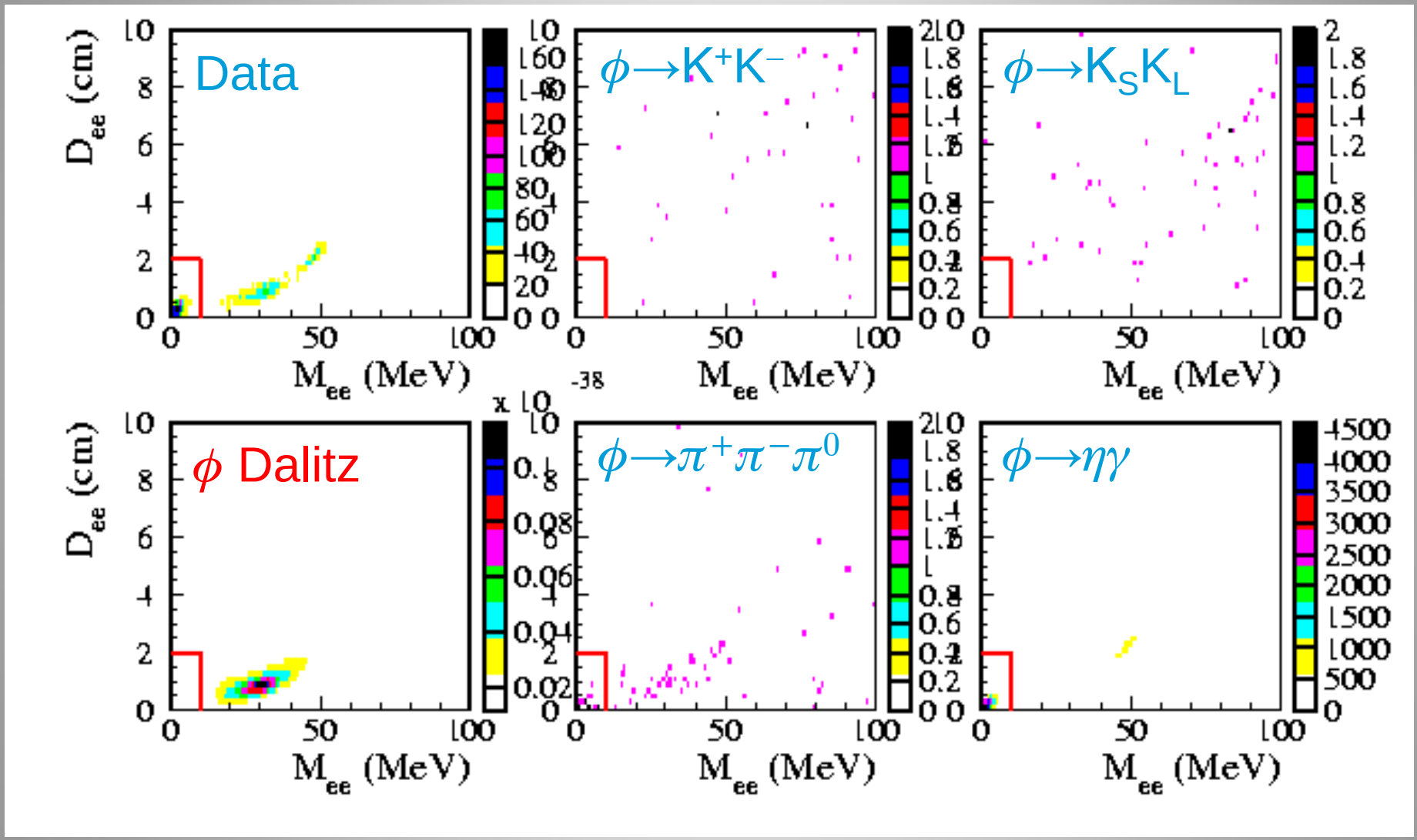
$\Phi \rightarrow \eta\gamma$ background with the same signature of the signal is mainly due to photon conversion on beam pipe (BP) or drift chamber walls (DCW) of the primary photon.



These kind of events are rejected tracking back to BP/ DCW surfaces the two e^+, e^- candidates and reconstructing the e^+e^- invariant mass (M_{ee}) and the distance between the two particles (D_{ee})

These variables are small if coming from photon conversion

Conversions on BP after $M_{miss}(ee)$ cut



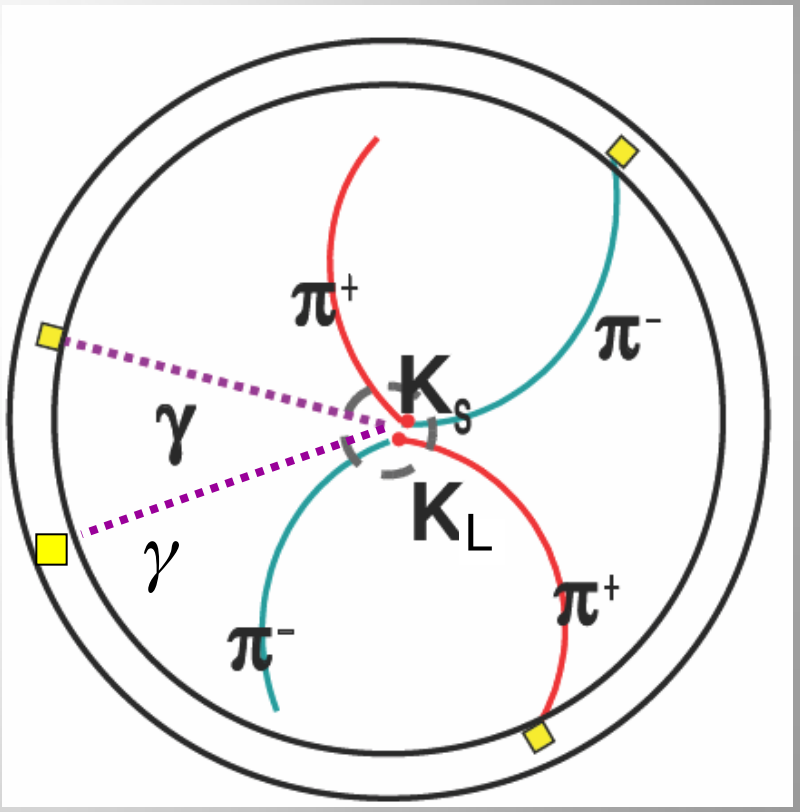
Cut: $M_{ee} < 10$ MeV & $D_{ee} < 2$ cm

Most of the $\Phi \rightarrow KK$ and $\Phi \rightarrow \pi^+\pi^-\pi^0$ events surviving analysis cuts have more than two pions in the final state. They can be rejected using Time-of-Flight (ToF) to the calorimeter when an EMC cluster is connected to the track

DT = T_{track}-$T_{cluster}$ variable evaluated in both electron and pion hypotheses

T_{track} is the ToF evaluated using track length and β assuming mass

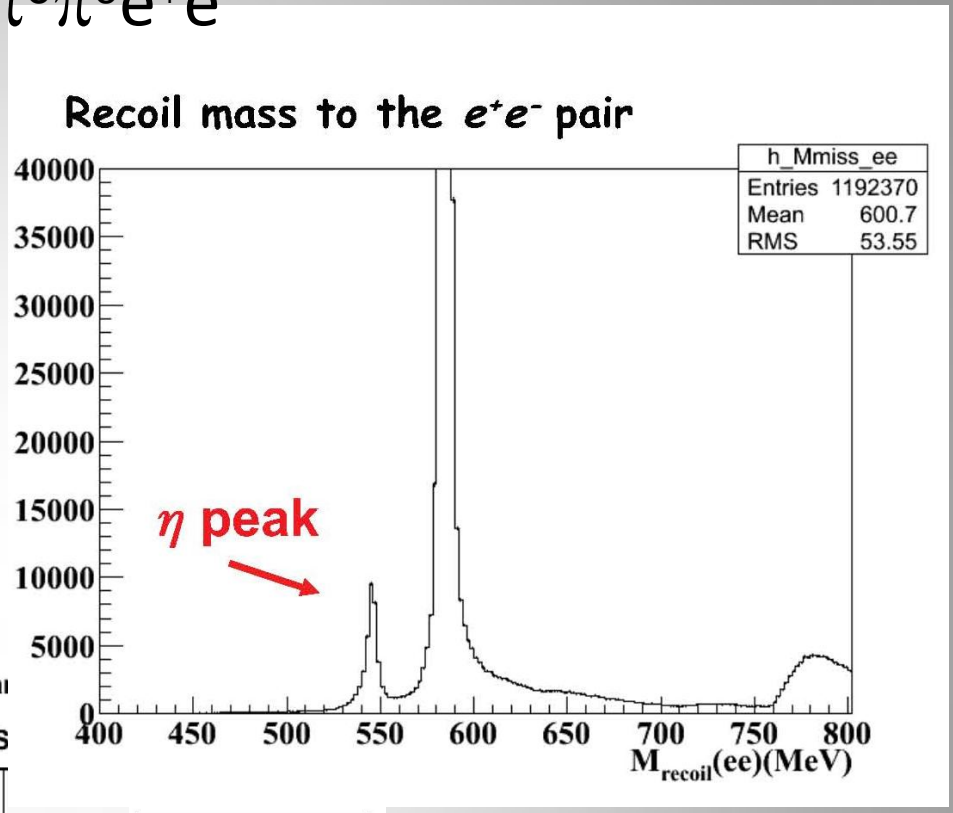
$T_{cluster}$ is the arrival time to the EmC

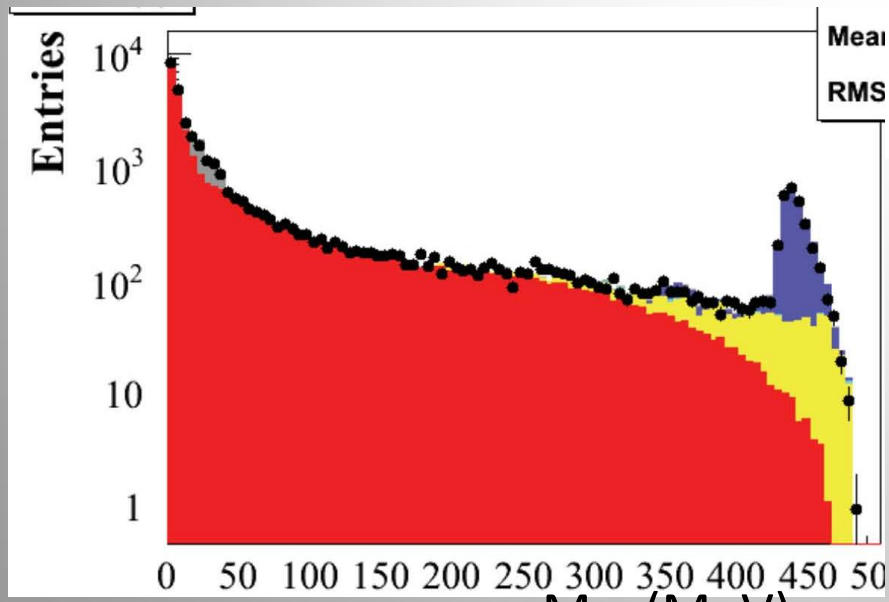


$$\Phi \rightarrow \eta e^+e^- \rightarrow \pi^0\pi^0\pi^0 e^+e^-$$

Easier than the charged channel

- 2 tracks and 6 prompt γ's candidates
- $536 < M_{recoil} < 554$ MeV
- Photon conversion + ToF cuts



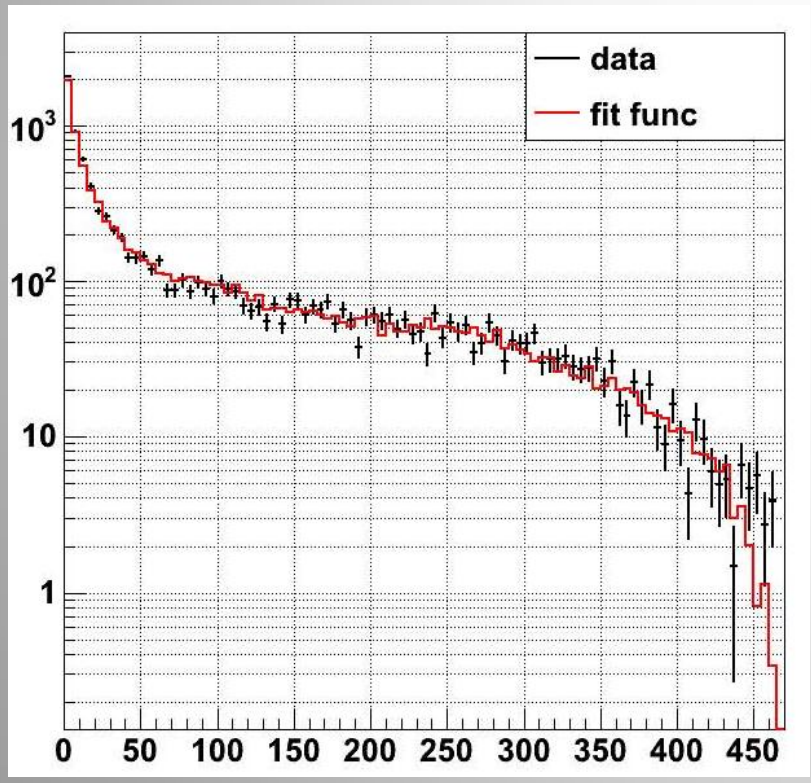


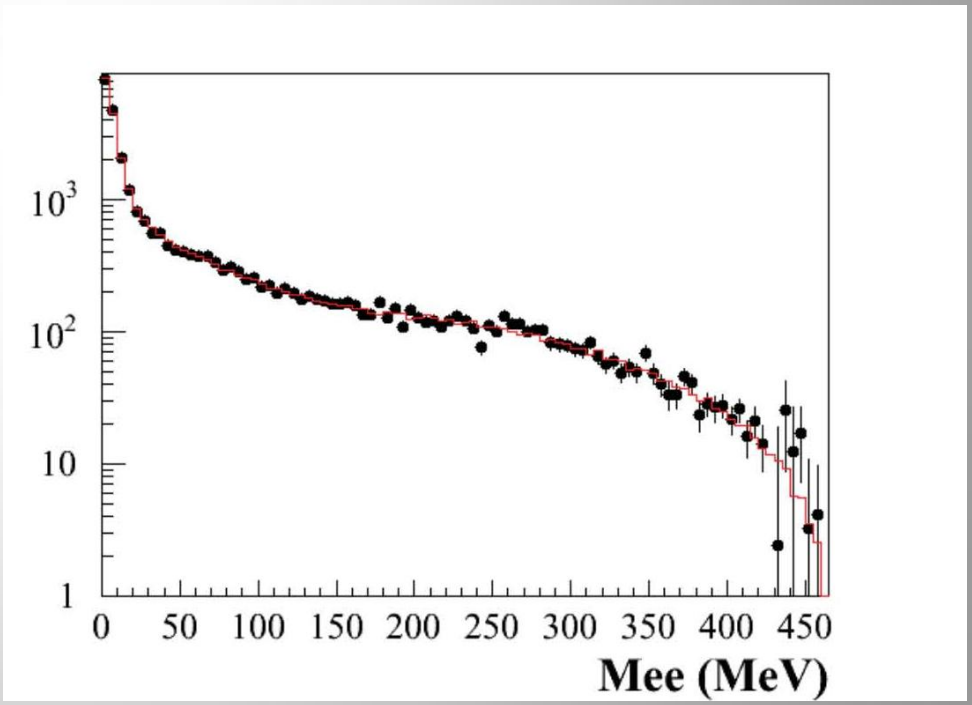
- Data
- $\phi \rightarrow \eta e^+e^-$
- $\phi \rightarrow \omega \pi^0$
- $\phi \rightarrow K^+K^-$
- $\phi \rightarrow K_S K_L$
- $\phi \rightarrow \rho\pi$
- $\phi \rightarrow \eta\gamma$

Signal and bckg components before conversion and ToF cuts

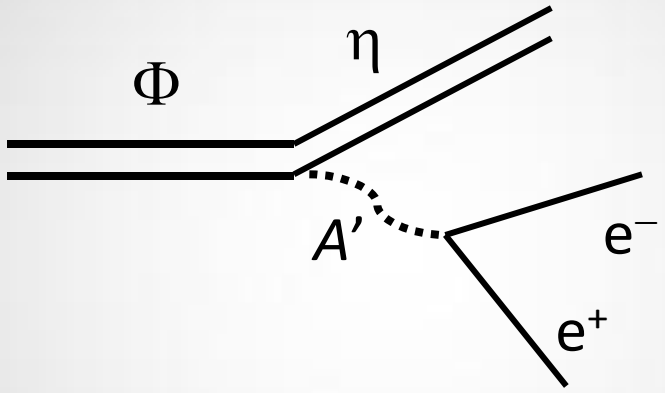
After all cuts ~14000 events survive in the charged channel and ~ 29000 in the neutral one

The two fits to the M_{ee} spectrum agree with each other. Systematics under study. *Final result due for the fall 2012*





These $V \to P e^+ e^-$ are also useful to search for light non standard bosons A', weakly coupled to ordinary matter through a kinetic mixing with the photon via a parameter ε, to be determined by the experiment, so that $BR(V \to PA') = \varepsilon^2 \, BR(V \to P\gamma^*)$



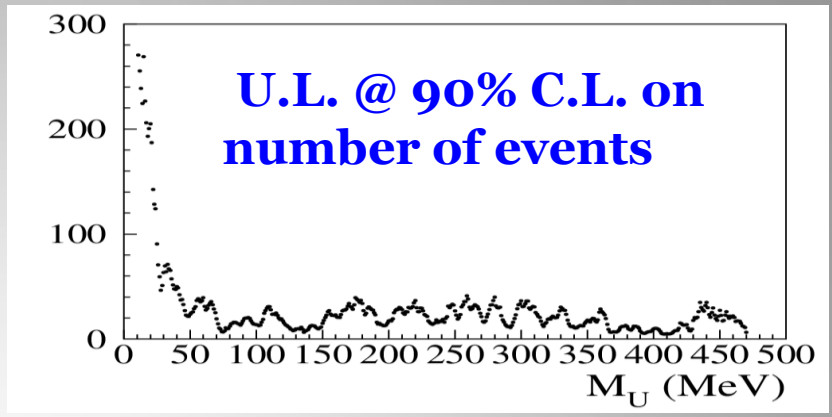
The A' is also searched for in e^+e^- collisions (BaBar, BESIII, KLOE) as well as in e-p scattering experiments (JLAB, MAMI) and are mainly motivetad by data-driven models of dark matter

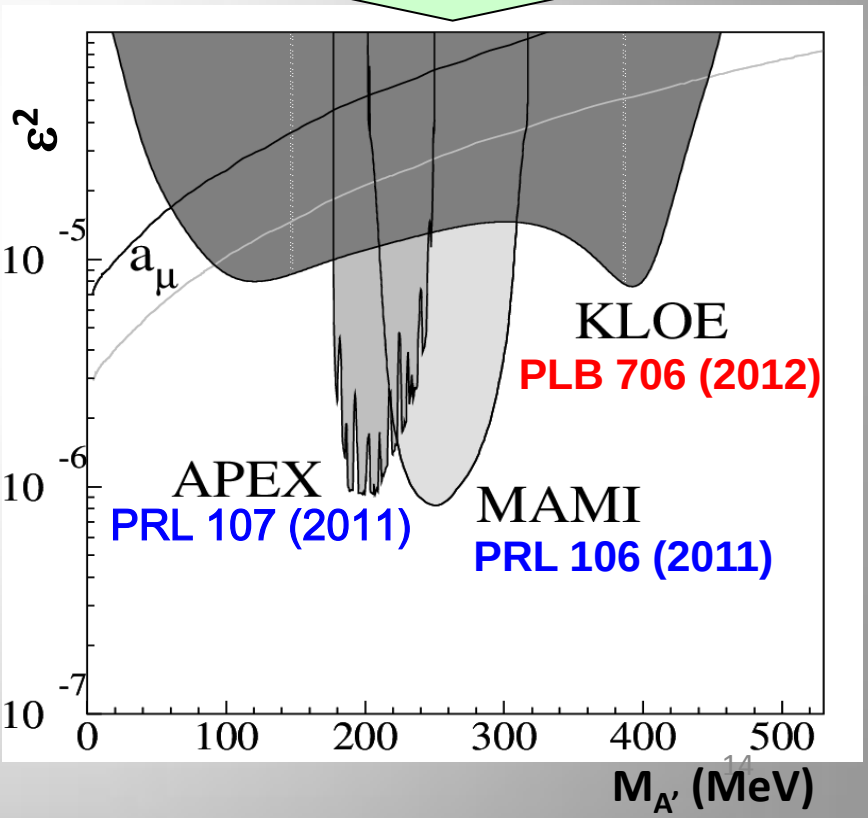
Signal can be observed by the presence of a sharp peak in the M_{ee} distribution

Using only the charged decays sample we have published a competitive limit in the $M_{A'}$ - ε^2 as reported in the nearby plot

Standard Dalitz decay background measured bin-by-bin by sidebands, so independently of the determination of the FF

Inclusion of the neutral channel expected for October





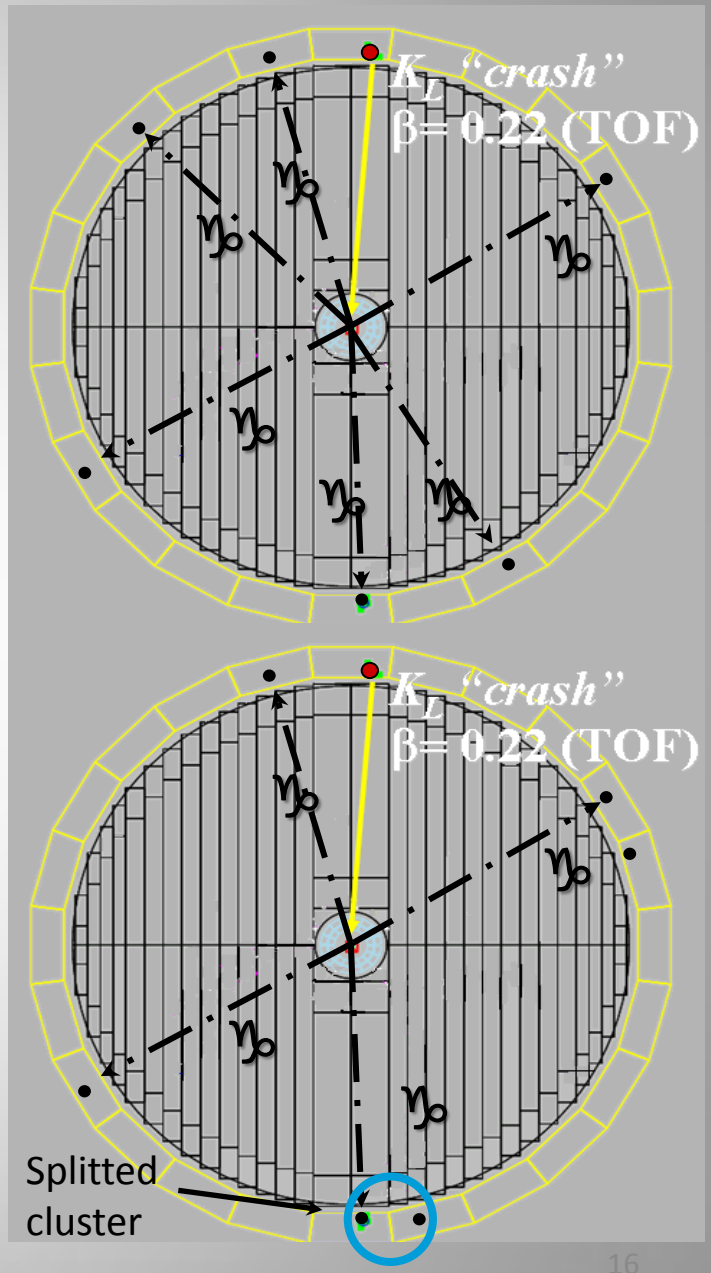
A workshop is being organized on these issues in Frascati next October 16-19. Registration is still open. Everybody is welcome!

http://www.lnf.infn.it/conference/dark

$K_S \rightarrow 3\pi^0$

Purely CP violating decay.
SM expectation for *BR* ~2×10^{-9}

- K_S tagged with K_L interactions on calorimeter
- 6 prompt γ's required
- Main background due to $2\pi^0$ events with 2 fake photons
- Analysis based on kinematic fits on $2\pi^0$ and $3\pi^0$ hypothesis



Previous KLOE result based on 450 pb^{-1}, 2 observed events with 3.1 expected background $BR(K_S \rightarrow 3\pi^0) < 1.2 \times 10^{-7}$ @ 90% CL

Analysis updated by:

- Using the full KLOE statistics
- Improving clustering algorithm to reduce split cluster probability
- Refining K_S tagging alghoritm

No event observed in data with zero events expected from MC background and 0.2 for signal MC

$$BR(K_S \rightarrow 3\pi^0) < 2.7 \times 10^{-8} \text{ @ 90\% CL}$$

New KLOE result! Paper in preparation

Observation of $K_S \rightarrow 3\pi^0$ is an unambigous sign of CP violation in mixing and/or decay

$$\eta_{000} = \frac{< 3\pi^0 \mid T \mid K_S >}{< 3\pi^0 \mid T \mid K_L >} = \varepsilon + \varepsilon'_{ooo}$$

To lowest order in χPT

$\varepsilon'_{000} = -2\varepsilon'$

$$|\eta_{000}| = \sqrt{\frac{\tau_L \cdot BR(K_S \rightarrow 3\pi^0)}{\tau_S \cdot BR(K_L \rightarrow 3\pi^0)}}$$

Our result implies

$|\eta_{000}| < 0.018$ @ 90% CL

The result also points to the possibility for a first observation of the process with the full KLOE-2 statistics

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

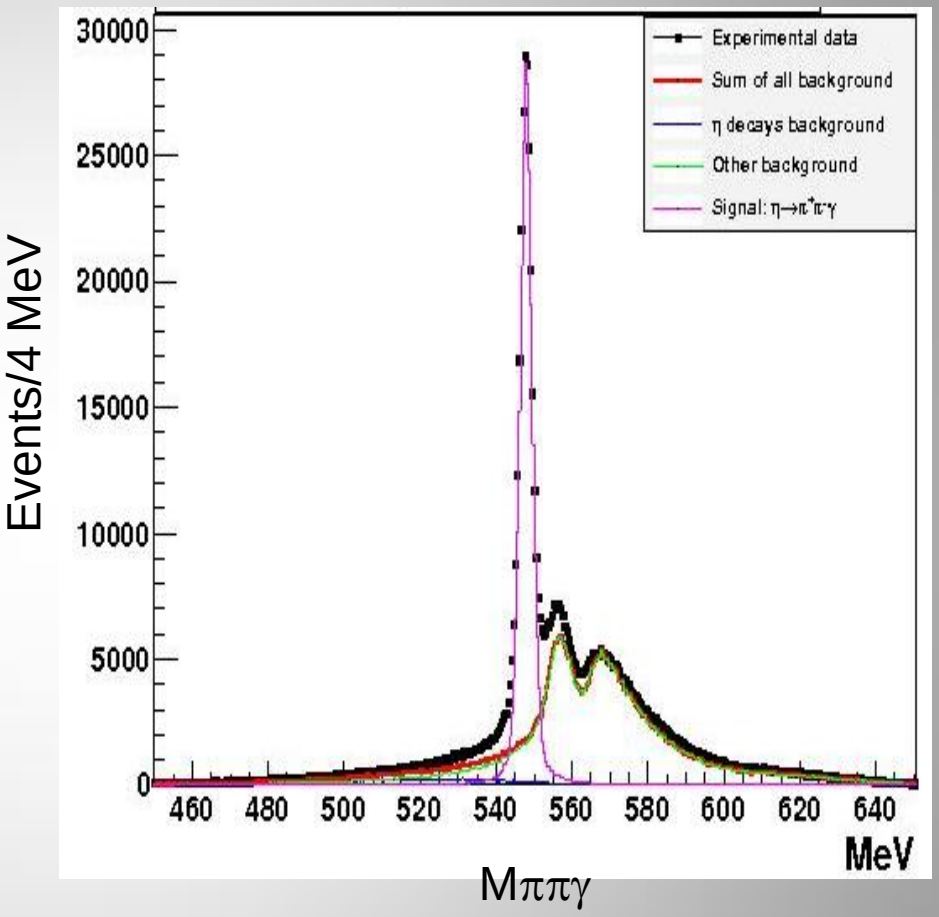
The $\eta \to \pi^+\pi^-\gamma$ decays are expected to receive contributions by both a resonant (mostly ρ) and a contact term (CT) whose relative strenghts are not fixed by the theory

The present PDG world average for $\Gamma(\eta \to \pi^+\pi^-\gamma)$ = (60.±4) eV favours a strong contribution of the CT:

$$\Gamma_{\text{wCT}} = (56.3 \pm 1.7)\ \text{eV},\ \Gamma_{\text{w/oCT}} = (100.9 \pm 2.8)\ \text{eV},$$

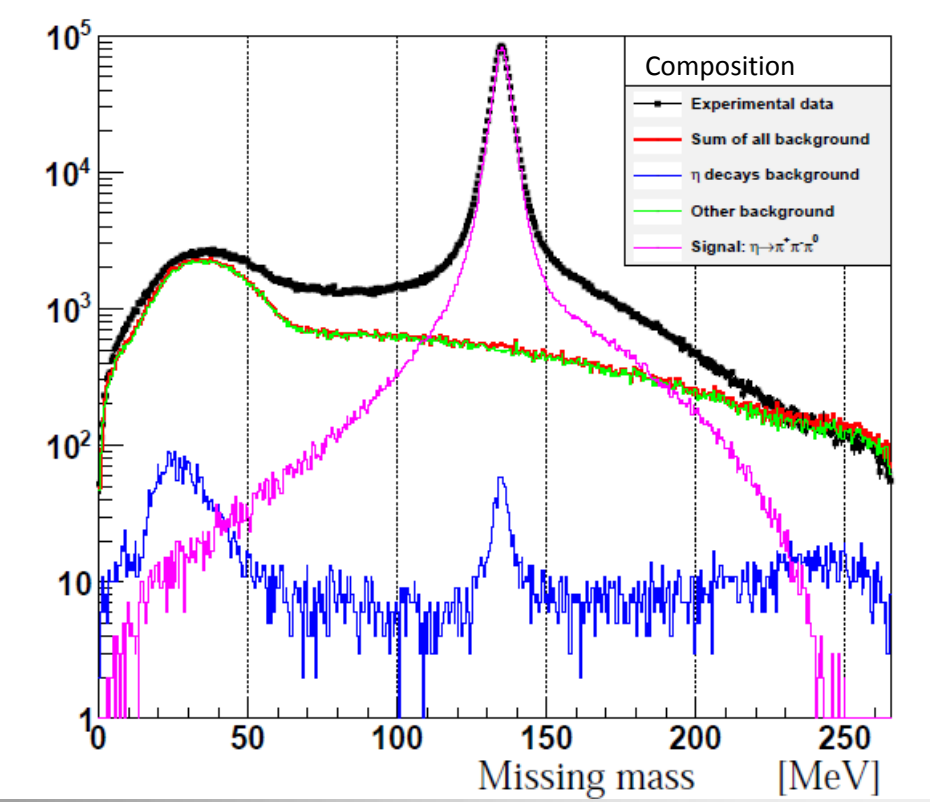
A few years ago, CLEO has issued a new result for the ratio $BR(\eta \to \pi^+\pi^-\gamma)\ /BR\ (\eta \to \pi^+\pi^-\pi^0)$ which differs by more than 3σ by the average of all the previous measurements

- 2 tracks and $\geq$2 prompt γ's required
- 1 γ with $E_\gamma > 250$ MeV
- Kinematics of Φ two-body and η decay constrain γ_η energy and direction
- Main background from $\Phi \rightarrow \pi^+\pi^-\pi^0$ rejected by cutting on opening angle between photons in the π^0 reference frame
- Background from double radiative bhabhas rejected with Time-of-Flight



Final event selection imposing 539.5 MeV < $M_{\pi\pi\gamma}$ < 554.5 MeV

$\eta \to \pi^+\pi^-\pi^0$ decays used as control and normalization sample

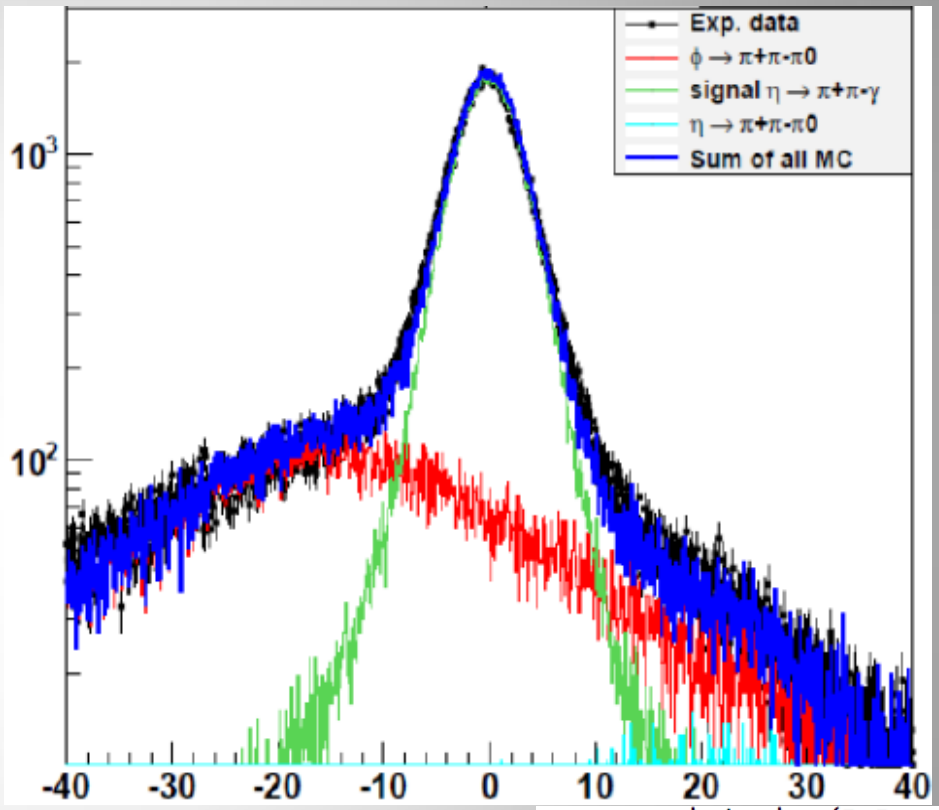


recoil mass against $\pi^+\pi^-\gamma$ (MeV)

- Same runs and preselection used as for $\pi\pi\gamma$ signal
- Very pure sample B/S = 0.65%
- Event counting from fit to M_{recoil} from $\pi\pi\gamma$ system
- Selection efficiency ~ 22%
- More than 10^6 selected events

- Used data sample 558 pb^{-1}
- ε = (21.31 ± 0.04)%
- B/S = 10%
- Signal counting from fit to $E_{miss} - P_{miss}$ of the $\pi\pi\gamma_{\Phi}$ system
- N_{ev} = 204950 ± 450

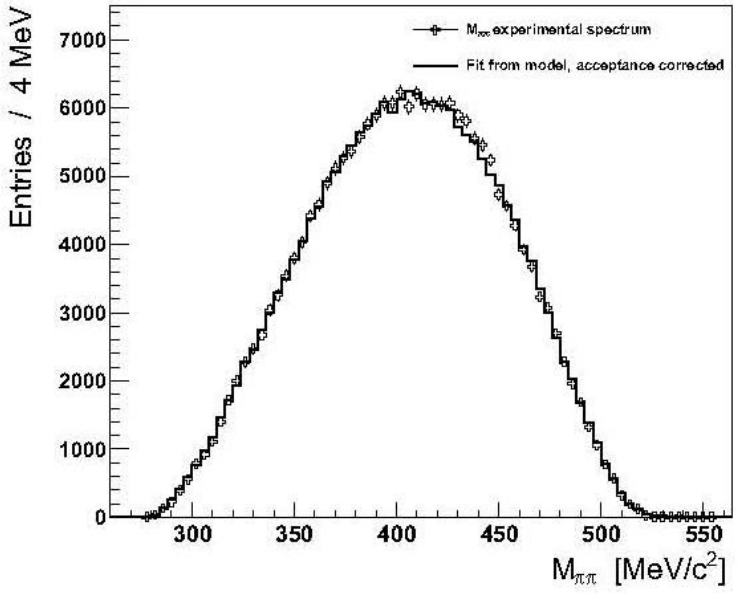
$$E_{\gamma_\eta} = \sqrt{s} - E_{\pi+} - E_{\pi+} - E_{\gamma_\phi}$$
$$|\vec{p}_{\gamma_\eta}| = |\vec{p}_{\pi+} + \vec{p}_{\pi+} + \vec{p}_{\gamma_\phi}|$$



$$BR(\eta \to \pi^+\pi^-\gamma)/BR(\eta \to \pi^+\pi^-\pi^0) = 0.1856 \pm 0.0005 \pm 0.0028$$

Consistent with CLEO but with a factor ~3 better precision

We have also fit the $M_{\pi\pi}$ spectrum according to the model-independent parameterization of *Stollenwerk et al. PLB 707 (2012), 184*



$$\mathcal{A}(\delta,\alpha) = \underbrace{A(\delta)}_{\text{fitted to BR}} \left(\underbrace{1 + \alpha\, s_{\pi\pi} + \mathcal{O}(s_{\pi\pi}^2)}_{\text{extracted from the spectrum}} \right) \underbrace{F_V(s_{\pi\pi})}_{\text{universal}}$$

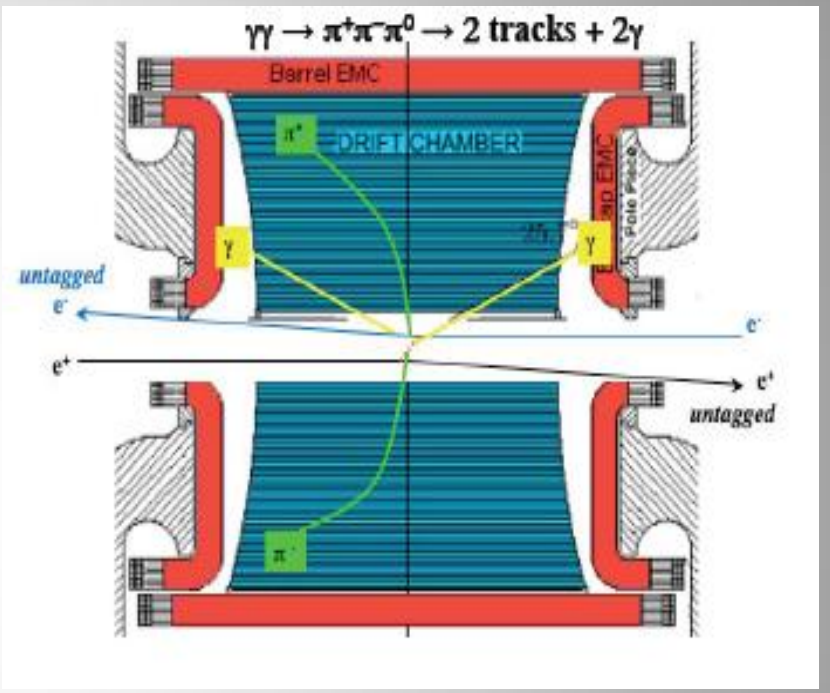
Reaction-specific term. Simple ChPT predicts $\alpha \sim 1$ GeV^{-2}

We have obtained

$$\alpha = 1.32 \pm 0.08\ ^{+0.1}_{-0.09} \pm 0.002_{\text{theo}}\ \text{GeV}^{-2}$$

previous measurement $\alpha_{WASA} = 1.89 \pm 0.25 \pm 0.59 \pm 0.002$ GeV^{-2}

In early 2006 KLOE has collected 240 pb^{-1} of data @E_{CM} = 1 GeV, to study continuum physics far from the dominant background due to Φ production and decay

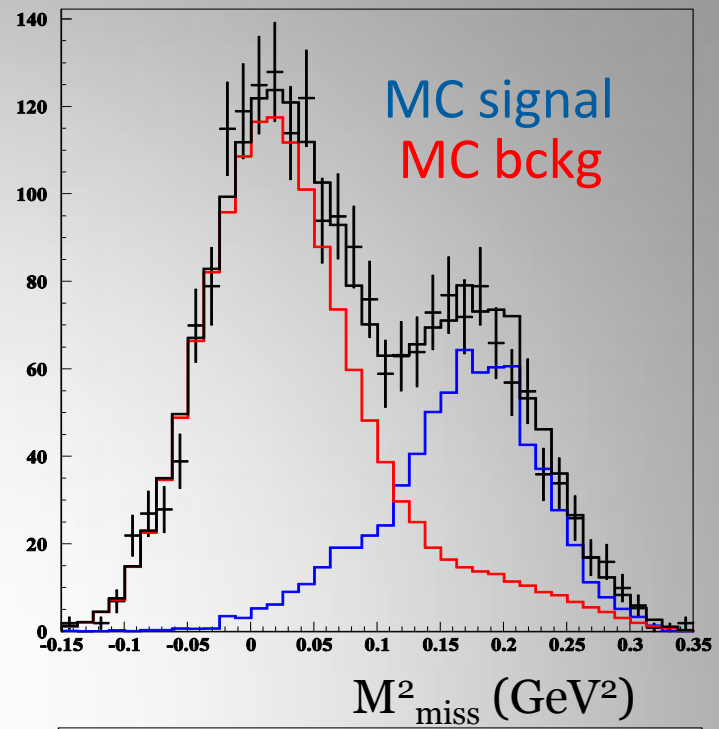


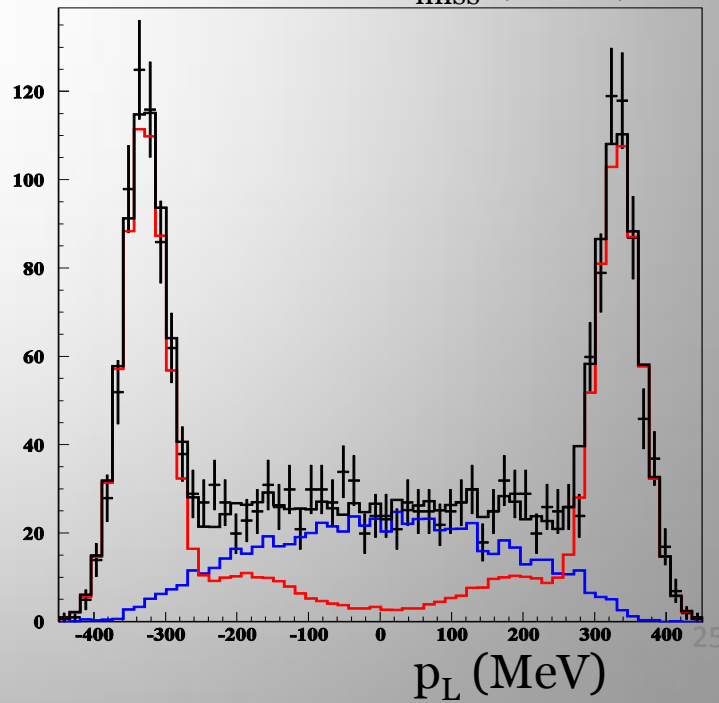
In particular we realised that we could make precision studies of the $e^+e^- \to e^+e^-\eta$ transitions, relevant for the determination of the LbL term in the calculation of the muon g-2, and for the measurement of the 2 photon width of the η

VALUE (keV)	EVTS	DOCUMENT ID		TECN	COMMENT	$\sqrt{s}$ (GeV)
0.510±0.026 OUR FIT						
0.510±0.026 OUR AVERAGE						
0.51 ±0.12 ±0.05	36	BARU	90	MD1	$e^+e^- \to e^+e^-\eta$	7.2-10.4
0.490±0.010±0.048	2287	ROE	90	ASP	$e^+e^- \to e^+e^-\eta$	29
0.514±0.017±0.035	1295	WILLIAMS	88	CBAL	$e^+e^- \to e^+e^-\eta$	9.4-10.6
0.53 ±0.04 ±0.04		BARTEL	85E	JADE	$e^+e^- \to e^+e^-\eta$	34.6

$e^+e^- \rightarrow \eta e^+e^- \rightarrow \pi^0\pi^0\pi^0 e^+e^-$

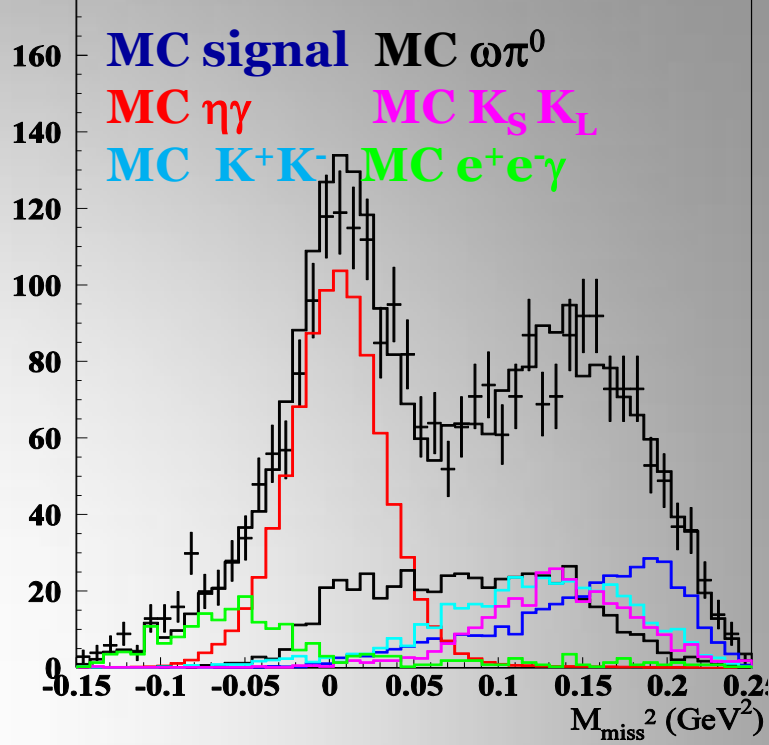
- 6 and only 6 prompt γ's
- No tracks in the DC
- Kinematic fit on the 3 γ pairs to the π^0 mass
- Kinematic fit of the 6 γ 's to the η mass
- $E_{\gamma 1} < 260$ MeV
- Signal counting from a 2D fit to the squared missing mass and longitudinal momentum of 6γ's with background level free
- ~720 signal events found

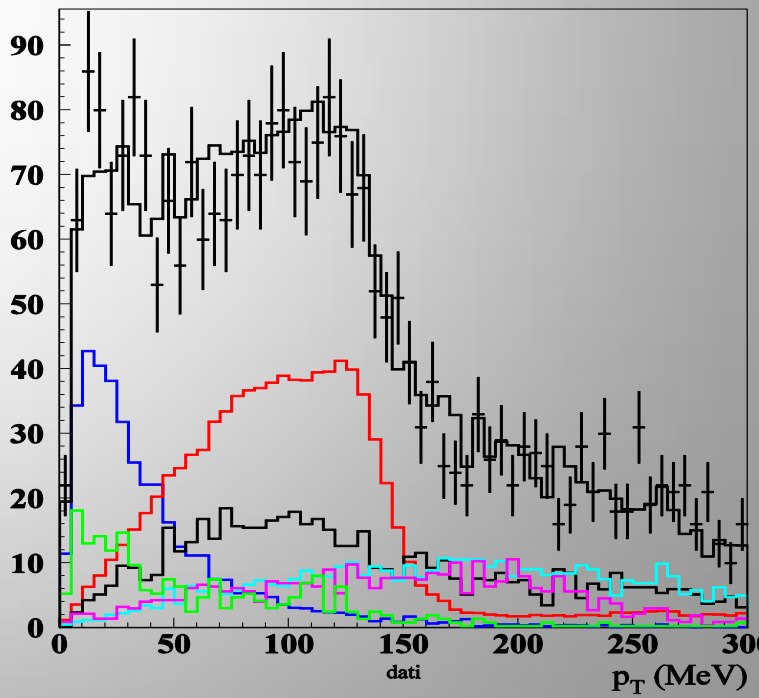




$e^+e^- \to \eta e^+e^- \to \pi^+\pi^-\pi^0\pi^0 e^+e^-$

- 2 prompt γ's and 2 tracks
- Kinematic fit on the γ pair to the π^0 mass
- Kinematic fit of the 2γ 's and the $2\pi^{\pm}$ to the η mass
- π/e discrimination based on ToF and cluster shape
- Signal counting from a 2D fit to the squared missing mass and transverse momentum with background level free except for continuum $\eta\gamma$ measured independently by us
- ~390 signal events found





Charged channel:

$\sigma(e^+e^- \rightarrow e^+e^-\eta, \sqrt{s}=1\ \text{GeV}) =$

$[\ 34.5 \pm 2.6_{\ \text{stat}} \pm 0.9_{\ \text{syst}} \pm 0.4_{\ \text{BR}(\eta\rightarrow\pi^+\pi^-\pi^0)}\ ]\ \text{pb}$

Neutral channel:

$\sigma(e^+e^- \rightarrow e^+e^-\eta, \sqrt{s}=1\ \text{GeV}) =$

$[\ 32.0 \pm 1.5_{\ \text{stat}} \pm 0.8_{\ \text{syst}} \pm 0.2_{\ \text{BR}(\eta\rightarrow 3\pi^0)}\ ]\ \text{pb}$

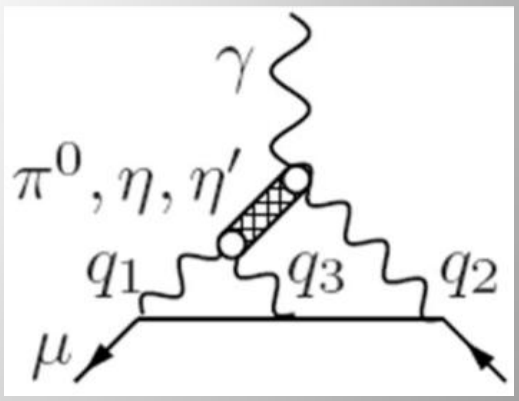
Both KLOE measurement more precise than any other single previous measurement

Final paper with combination of the two and the value of $\Gamma(\eta\rightarrow\gamma\gamma)$ *will be issued in the fall*

Two photon physics is one of the main physics topics for the run of the upgraded DAΦNE with the upgraded detector KLOE-2

For the purpose we have installed two pairs of new detectors (the $\gamma\gamma$ taggers) to detected the scattered electrons/positrons typical of these reactions

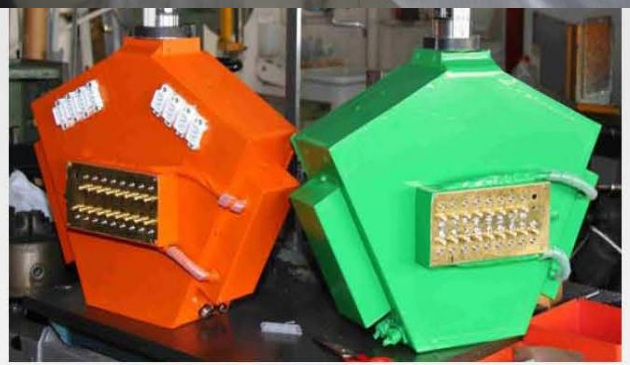
One of the main goals is to measure $\Gamma(\pi^0 \to \gamma\gamma)$ with 1% precision and to determine the $\pi^0 \to \gamma\gamma^*$ transition form factor at low Q^2. This would allow decreasing the theoretical LbL error on the μ g-2 by a factor 2 and requires acquiring ~ 5 fb^{-1}

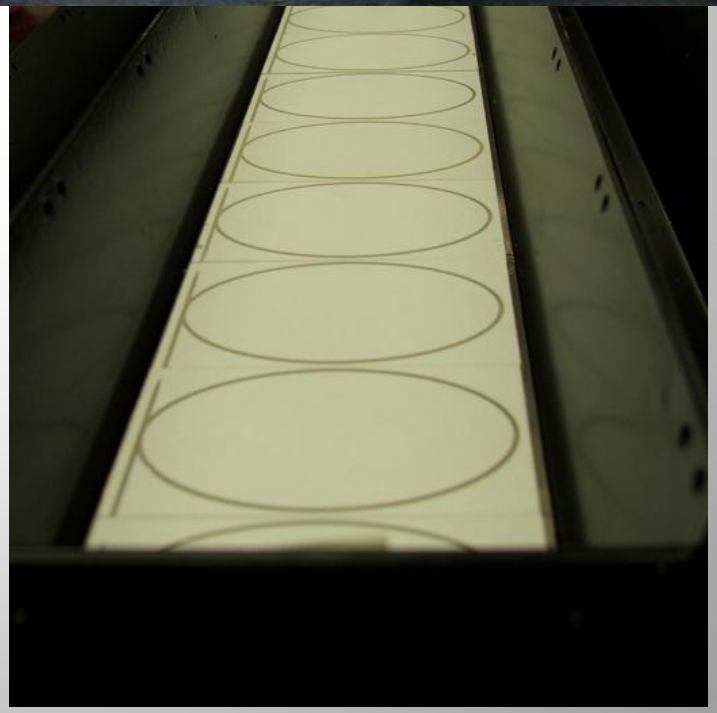


Other new subdetectors are under preparation to be installed in the fall of 2012, early 2013

- A 4-layers cylindrical triple-GEM detector to be used as internal tracker
- A tungten-scintillating tiles calorimeter to equip the low-β quadrupoles inside KLOE
- A forwad LYSO crystals calorimeter to detect very forward photons from the IP

With these new detectors we plan to collect $\sim$10 fb^{-1} in the following 3 years





In 2008-2009 the DAΦNE team has implemented a new interaction scheme which has allowed them to reach striking record performances in terms of both peak and integrated luminosity

Actually, during the run of the SIDDHARTA experiment, a non-magnetic nuclear physiscs detector, $L_{peak} = 4x10^{32}$ cm^{-2}s^{-1} and $L_{int} = 15$ pb^{-1}/day were obtained (factors 2-3 better than the 2005 KLOE run)

The implementation of this scheme to KLOE is being tried during the last ~10 months but at present results are not as satisfactory as we hoped

The machine has shown clear signs of hardware deterioration, which are being cured with care and dedication, however this requires time and money

There are also several subtle machine physics issues which require dedicated efforts to be understood and solved. For instance beam lifetimes are very short, which transaltes in very high backgrounds

At present, the reached luminosity is ~ the same we had in 2005, but backgound levels are higher by a factor of ~3

The Laboratory is putting all possible efforts to improve the situation. The next few monts will be crucial for the future of the project

Conclusions

The reach harvest of data acquired by KLOE in the first half of the last decade is still producing copious results in many different fields of physics

The implementation of a new interaction scheme for DAΦNE gives us serious hopes to increase this harvest considerably

Despite the many (un)expected difficulties experienced in the last months, the laboratory is trying its best efforts to let this hope become reality. The next few months will be crucial to understand if we are on the right path to success