Searches for dark forces with the KLOE-2 experiment

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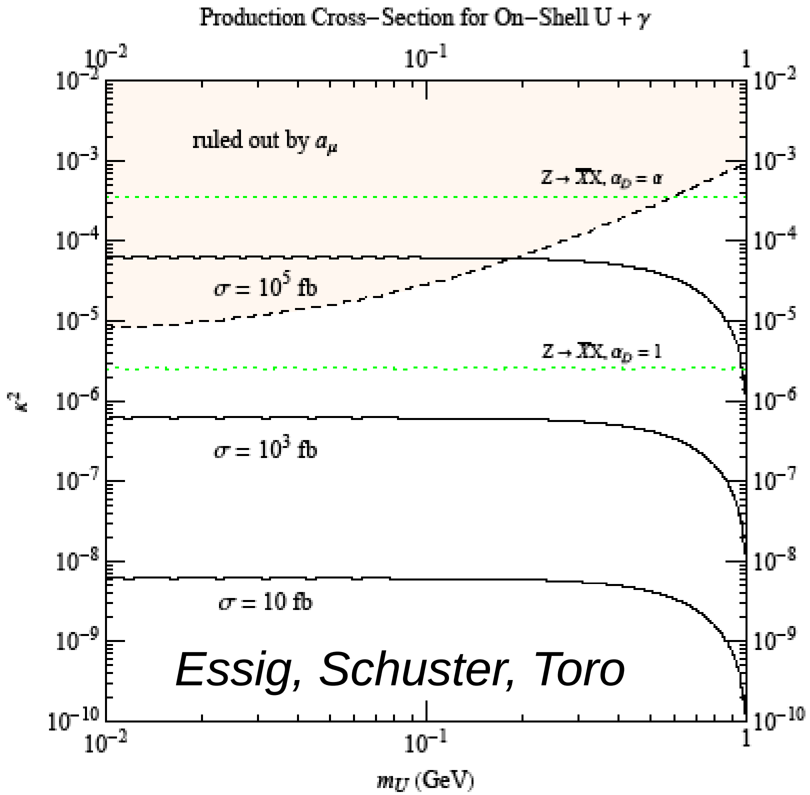
Dark Forces at KLOE?

Recently, several papers by many of the speakers (and organizers) of this workshop, have pointed out that the KLOE experiment at the Frascati ϕ-factory DAΦNE can contribute to the searches for the dark forces

Basically, this is possible since DAΦNE is the highest luminosity e^+e^- machine presently running at the lowest possible energy, *<u>where production cross sections are expected to be higher due to 1/s scaling law</u>*



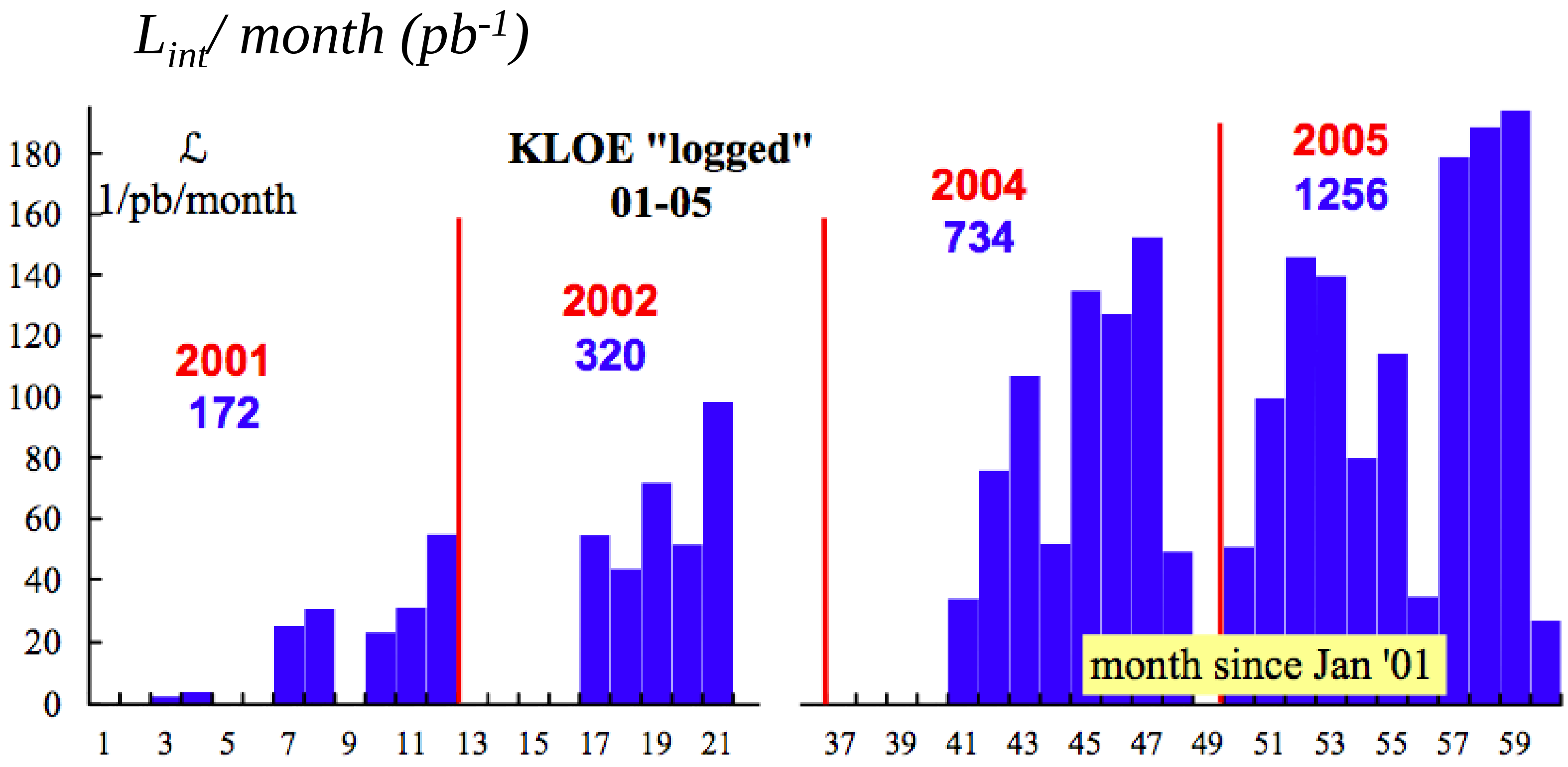
From KLOE to KLOE-2

Between year 2000 and 2006 KLOE has acquired ~2.5 fb^{-1} around the $\Phi(1020)$ resonance peak and 0.25 fb^{-1} off peak.

This results into the same discovery potential (or slightly less) than the present B-factories for *almost* all the possible channels with some interesting exceptions

Although the analysis of the present data set is still certainly worthwhile, a step forward in the field from e^+e^- collisions calls for an increase of the acquired luminosity by ~an order of magnitude

KLOE data taking



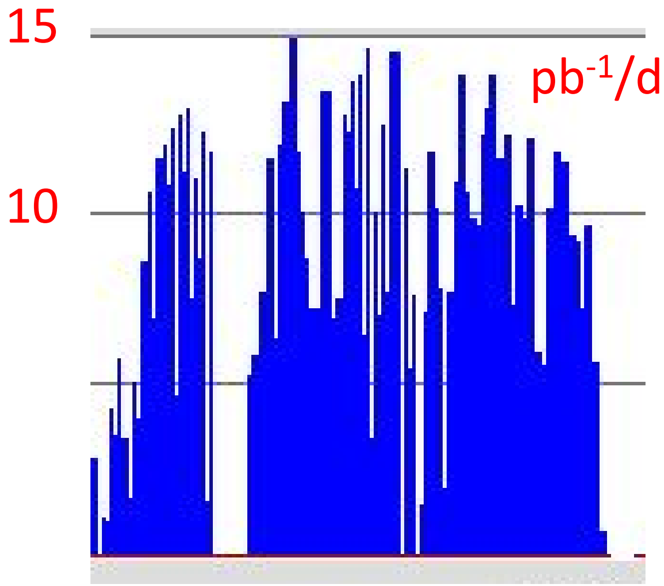
Best day: 10 pb^{-1}

Best month: 194 pb^{-1}

The "new" DAΦNE

Since the beginning of 2008, DAΦNE has implemented a new interaction scheme based on the use of a large Piwinski angle in combination with a crabbed waist induced by properly designed sextupoles

Results obtained during the run of the SIDDHARTA experiment have been extremely positive: an increase of the peak luminosity by a factor of ~3 and of the integrated luminosity by a factor ~2 has been achieved



The KLOE-2 project

The above numbers mean that we have now a ‘new’ machine capable of delivering ~4 fb^{-1}/year, even accounting for a reasonable duty cycle

There is still space for improvements, both in terms of increasing the currents and in terms of operation efficiency

The goal of having the present KLOE statistics increased by ~ an order of magnitude within a few years is therefore feasible

On the basis of our past experience we have also proposed a few detector upgrades which will help us increasing the effectiveness of the data collection in terms of physics reach

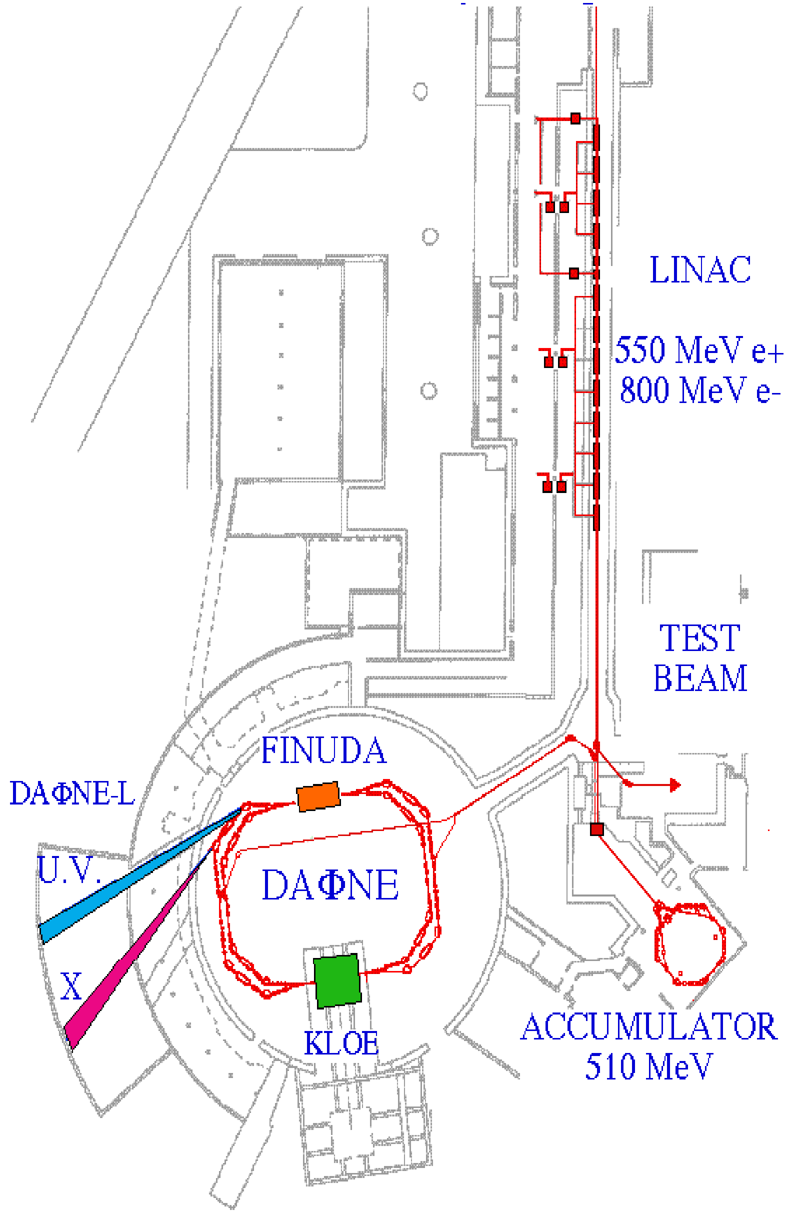
DAΦNE for pedestrians

DAΦNE is a ~300 m long symmetric e^+e^- machine operating at $E_{c.m.}$ = 1020 MeV (Φ resonance peak)

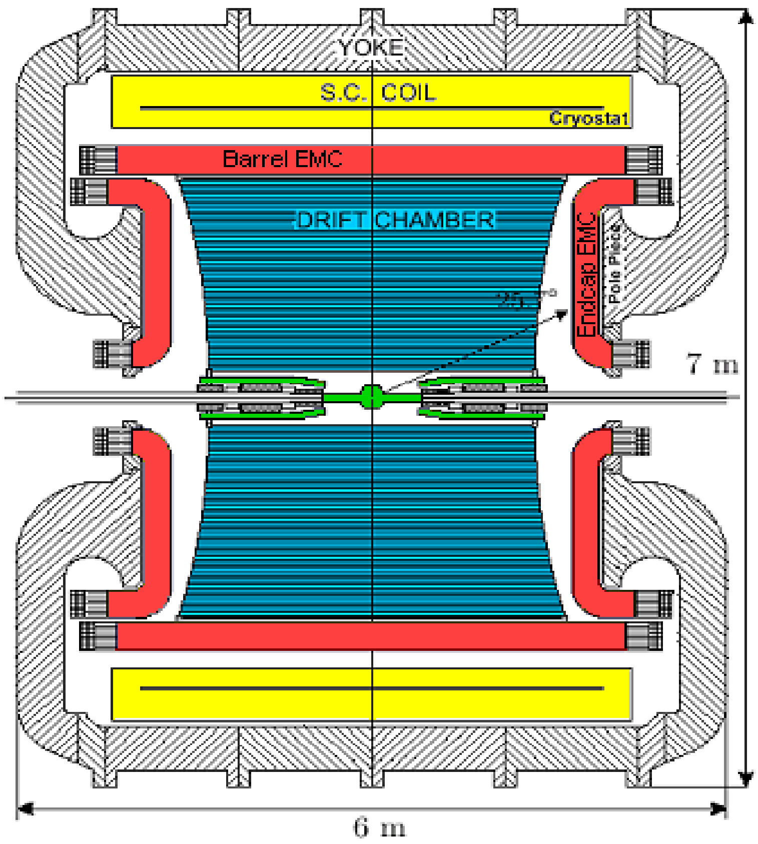
The main event fluxes are:
(in million events/pb^{-1})

- K^+K^- : 1.5
- K_SK_L : 1.
- ρπ : 0.5
- ηγ : 0.04

Moreover, one has to consider also ~ 5 million Bhabha events/pb^{-1} whithin detector acceptance (depending on the E_γ cutoff energy)



The KLOE detector



❖ **Superconducting coil** *B* = 0.52 T

❖**Be beam pipe** (0.5 mm thick), spherical 10 cm radius

❖**Electromagnetic calorimeter**
Lead/scintillating fibers (1 mm ∅) 4880 PMT's, 15 X_0

❖**Drift chamber**
(4 m ∅ × 3.3 m) 90% He + 10% IsoB, CF frame, 12582 stereo, single sense wire, "almost squared" cells

❖**Quadrupole calorimeter**

The proposed upgrades

We have proposed two major modifications to the detector:

1. The insertion of a thin *internal tracker* at a radius of $12.7\ \mathrm{cm} < R < 23\ \mathrm{cm}$, to increase the acceptance for low momentum particles and to improve the resolution on charged decay vertices
2. The insertion of very *low angle crystal calorimeters* to increase the acceptance for photons from ~22° to ~8° in polar angle

The R&D phase for these new subdetectors is essentially completed, their installation is planned for mid 2011.

Data taking plans

Our data taking plan is therefore the following

1. A first period of data collection between spring 2010 and summer 2011 with the basic KLOE detector
2. The implementation of the new subdetectors and a run of at least two years (2012/13) with the full KLOE-2

The program has been endorsed by the Laboratory's management but it still subject to some uncertainty (especially for point 2.) depending upon the plans for the longer term future of INFN, which are still under debate

Dark Forces at KLOE-2

The first discussions about these new line of reasearch were held in KLOE-2 only on April this year. Therefore it is still too premature to have results to be presented even preliminarly

We have decided to concentrate our efforts on three different reactions:

1. U (A') boson production in the reaction $e^+e^- \rightarrow l^+l^- \gamma$
2. Higgs'strahlung: $e^+e^- \rightarrow U\, h' \rightarrow l^+l^-$ + *missing energy*
3. U boson production in the reaction $e^+e^- \rightarrow l^+l^- \eta$

Radiative process

This is a relatively simple signature, very well studied for many other purposes (the hadronic cross section for instance)

However its cross section scales as $(1 + \cos^2(\theta))/\sin^2(\theta)$, thus it mostly in the forward direction resulting in a decrease in acceptance

Moreover it has exactely the same distribution of the QED background, so the process can be isolated by it only because it reasonates around the U boson mass

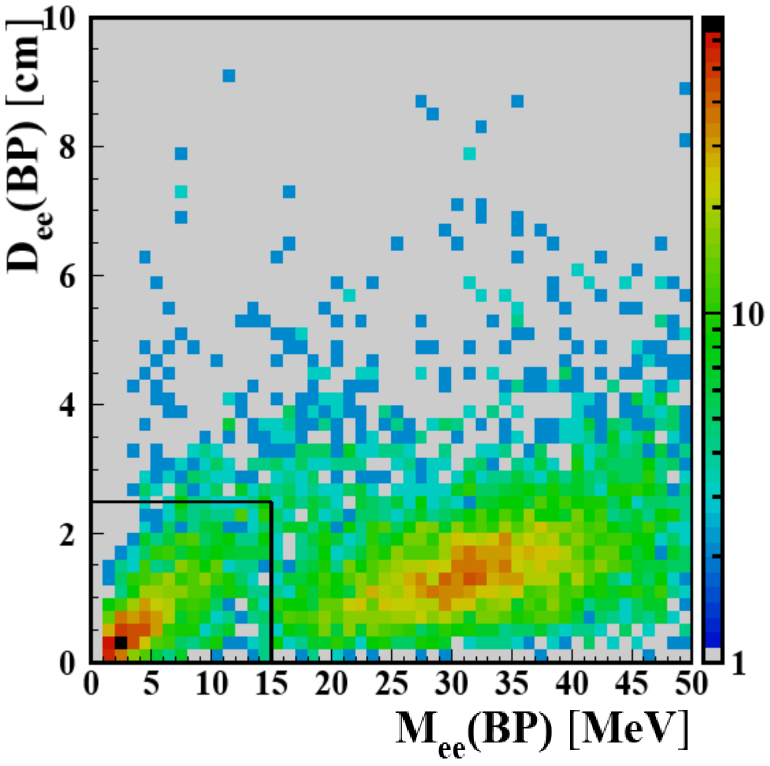
The invariant mass resolution of KLOE is ~1 MeV, but it is also relevant to keep the *non gaussian tails* under control

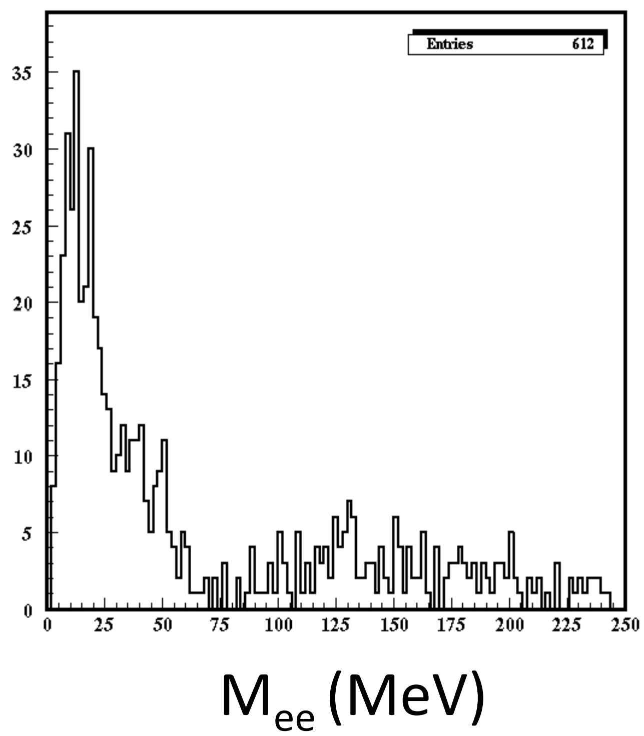
Gamma conversions

For low U masses, there is a further problem: the energy of the radiated photon is very close to the one of the standard $e^+e^- \rightarrow \gamma\gamma$ events. <u>Taking into account the KLOE calorimeter energy resolution, we obtain a 3σ separation from the $\gamma\gamma$ background for $M_u > 500$ MeV</u>

This effect is very dangerous for the e^+e^- channel, when combined with the probability of γ conversion on the beam pipe or on the DC wall

One can try to identify conversions using some smart alghoritm. For instance they have been reduced by as much as 70%, in the $\eta \to \pi\pi ee$ analysis. The invariant mass of the surving lepton pair is peaked at very low values





One reason of weakness is the distance (~ 30 cm) of the first tracking point from the decay vertex . The usage on the IT should be very beneficial under this respect

Lepton Identification

In principle both the electron and muon channels can be equally studied with KLOE(-2). Moreover in general muons should suffer of lower backgrounds from standard processes

However one has to keep in mind that while electrons are very well identified and separated from other particles, the same does not apply for muons

At our typical energies the standard HEP technique of identification via external μ-chambers does not work, making the π/μ separation an issue

U to invisible

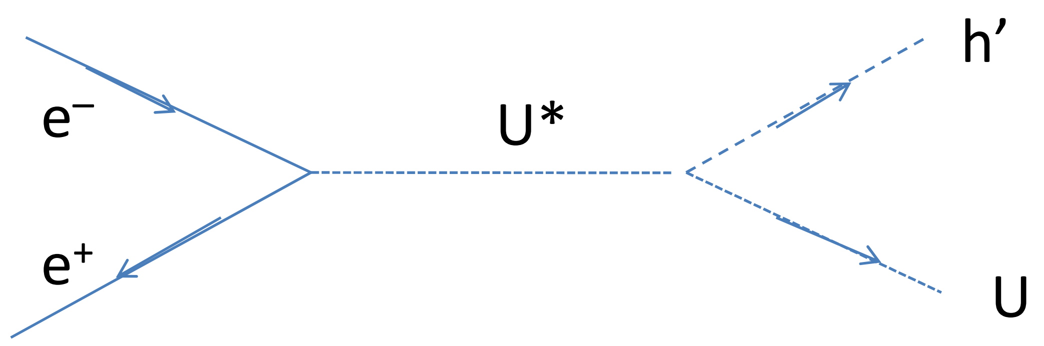
The above arguments apply if we assume that the U boson decays only to charged leptons. If it can decay also to neutrinos or to other invisible particles it can result in a single photon + missing energy signature.

An analysis for such a signature would require a dedicated trigger not presently in the KLOE trigger table. The implementation of this special trigger is not impossible in principle but it is not at present foreseen.

However such an experiment would require a calorimeter with an exceptional energy resolution, which is not the case of KLOE

Higgs'-strahlung

My favourite mechanism for secluded particles production is the higgs'-strahlung: $e^+e^- \rightarrow U\, h'$, which can have a cross section of order 1 pb at DAΦNE energies



If $m_{h'} < m_u$ then the higgs' is relatively long-lived, $O(10^{-9}$ s) thus escaping detection inside KLOE

The resulting signal would then be a lepton pair + missing energy

Why I like it

There are a number of advantages for this type of signature:

1. The QED background due to radiative processess is suppressed by the high ermeticity for γ's of the KLOE calorimeter
2. The missing energy must be equal to the missing momentum for photons but sizeably different for massive particles. Here the resolution is dominated by the DC
3. The angular distribution for the higgsstrahlung is proportional to $\sin^3(\theta)$, which enhances the geometrical acceptance and further suppresses the QED backgrounds

The two produced leptons have energies high enough to trigger the events with efficiencies > 90% for almost all possible combinations of m_U and $m_{h'}$, at least for the electron channel

A possible background specific to DAΦNE is $K_S \to \pi^+\pi^-$, with the parent K_L flying through the apparatus

This should be a problem only for the muon channel and for masses of the U boson close to m_K. It can however be well calibrated by using well tagged $K_S K_L$ events

If it turns out to be still a problem one can always think to make dedicated runs at $\sqrt{s} < 2m_K$

$\Phi \rightarrow U\eta$

Physics case: with the present statistics can probe the dark sector down to $\varepsilon \leq 10^{-3}$ (see LianTao's talk)

Basic advantage: DAΦNE is the only place where it can be studied.

The most dangerous background comes from the standard $\Phi \rightarrow \eta\gamma$ process with subsequent conversion of the photon on the beam pipe or on the DC wall.

Here the same considerations apply as for the cases discussed before.

$\Phi \rightarrow U\eta$

The η can be tagged by its $\gamma\gamma$ and/or $\pi^+\pi^-\pi^0$ decays

Detection efficiencies for these modes, as measured with the standard process, are very high.

A possible background to the $\gamma\gamma$ $\mu\mu$ channel can come from the misreconstructed/misidentified $\Phi\rightarrow\pi^+\pi^-\pi^0$ decays

A new student will start her thesis on this channel in a few weeks from now

Conclusions

1. We have started looking at the KLOE data collected so far and hope to have results to be presented in a few months from now
2. In the meanwhile we are preparing for a new period of data taking , starting next spring, with the goal of having the KLOE statistics increased by ~ an order of magnitude whithin a few years
3. Something we are missing is reliable Monte Carlo generators. Help from theorists is highly appreciated. Also advise about possible measurement strategies and interpretation of the data is welcome
4. KLOE-2 is an open collaboration: we have and will have a lot of physics to do : anyone interested in collaborating to this effort is very welcome