Dark Forces from KLOE-2 to SuperB

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SuperB Physics Workshop

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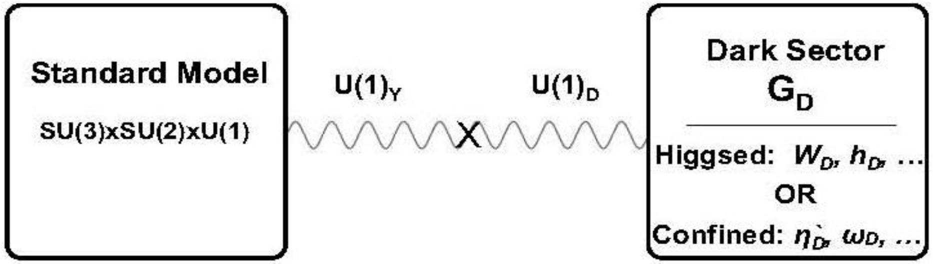
The idea of the existence of a hidden gauge sector weakly coupled with the SM through some mixing mechanism dates back to the early 80's. It has nowadays been reproposed by several authors, as a possible explanation of recent puzzling astrophysical observations

1. *P. Fayet: Phys.Lett. B95, 285 (1980)*
2. *P. Fayet: Nucl. Phys. B187, 184 (1981)*
3. *M. Pospelov, A. Ritz, M. Voloshin : Phys.Rev. D78:115012 (2008)*
4. *N. Arkani-Hamed, D. Finkenbeiner, T. Slatyer, N. Weiner: Phys.Rev. D79:015014 (2009)*
5. *E.J. Chun, J.C. Park: arXiv:0812.0308*
6. *M. Baumgart, C. Cheung, L.T. Wang, J. Ruderman, I. Yavin: arXiv:0901.0283*
7. *Y. Nomura, J. Thaler: arXiv:0810.5397*
8. *D. Alves, S. Behbabani, P. Schuster, J. Wacker: arXiv:0903.3945*
9. *many more…*

A particularly lively workshop on this models and on their consequences on low energy phenomelogy was held at SLAC on September 24/26 2009

Basically all of these models postulate the existence of a sort of “dark” world, sensitive to a specific gauge interaction G_D, that can provide an explanation to the dark matter quest

SM particles are not charged under G_D but, as specified above, can “feel” the new force because of mixing between it and the SM gauge interaction



The hidden symmetry can be Abelian or not, higgsed or confined. Depending on the choice one makes slightly different phenomenological consequences are obtained

Making the simplest choice of a $U(1)_D$ abelian symmetry, the natural connection with the Standard Model is through kinetic mixing

$$L_{KMix} = -\frac{\varepsilon}{2} b_{\mu\nu} F_{\gamma}^{\mu\nu}$$

Where b is the “dark photon” tensor, F is the SM hypercharge gauge boson and ε parametrizes the mixing strength, typically $\varepsilon \leq 10^{-3}$

This mixing can arise if there exists states which are charged under both U_D and U_Y, even if they are very heavy

Noticeably, Supersymmetry can be an elegant way to generate kinetic mixing at the GeV scale

The “dark photon”, dubbed with a large variety of names as *U*, *A’*, *V,* is the basic ingredient of all of these models. In models with a more complex gauge structure one can have several other higher mass bosons

After mixing, the *U* boson couples with the SM e.m. current J_{em}, giving rise to distinctive signatures for HEP and APP experiments

A natural, albeit not necessary, hypothesis is that the new symmetry is spontaneously broken by an Higgs-like mechanism. Therefore the existence of at least one other scalar particle, the *h’*, can be postulated

As in the SM, there is no firm prediction about the mass of the *h*’, nor of its relation with the mass of the *U* boson. This leads to important phenomenological consequences

A model with an underlying non-abelian symmetry and a confined sector gives rise to a rather complex dark particles spectrum

If the confinement scale is $\Lambda \sim 1$ GeV then one can produce hyperfine splittings of order ~ 100 kev, among “dark states”, as (as we will see) is possibly required by the data

A consequence of this is the existence of possible “dark mesons” or “dark glueballs” at the confinement scale with a rather rich phenomenology

(A model implementing the ideas above can be found in ref. 8)

Besides their theoretical appeal, these models have recently become more and more popular, because of two relevant reasons:

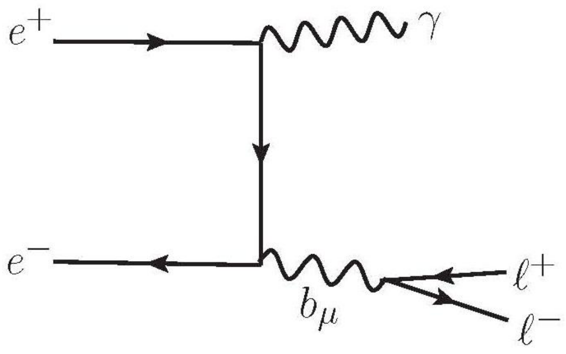
1. Several intriguing astrophysical observations from different experiments (FERMI, PAMELA, DAMA, INTEGRAL) can be interpreted in terms of the existence of a dark gauge interaction with at least one *light* (GeV-ish) force carrier
2. This hypothesis can be *tested* at present or future low energy facilities either using e^+e^- interactions, or $e^\pm N$ fixed target experiments, or via rare mesons decays

There are a few distinctive signatures to look at e^+e^- colliders

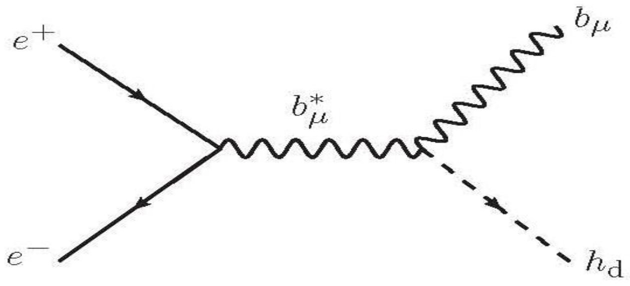
In general, cross sections of these processes scale with 1/s, so that in principle lower energy machines are favourite with respect to higher energy ones

However, the latter are favourite by the larger available phase space, and by the fact that their luminosity tends to compensate the lower fluxes, basically by the same amount

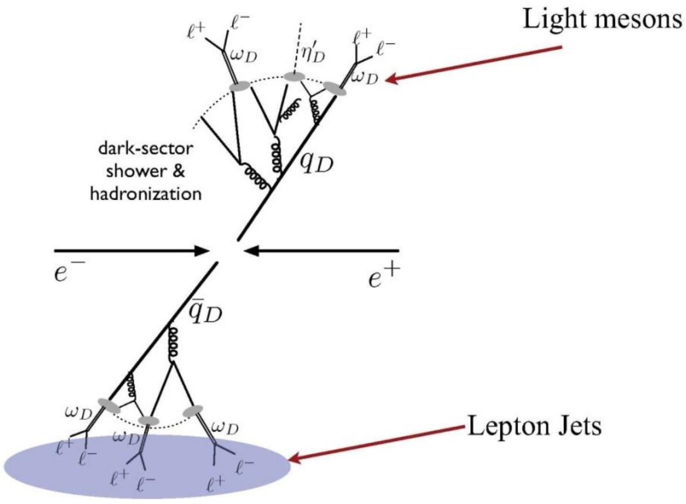
Therefore, there is complete synergy between all the possible searches at DAΦNE, BESIII, and present and future B factories



“Dark photon” (*U* boson) resonant production in $e^+e^- \rightarrow l^+l^-\gamma$ events



“Higgs’-strahlung” in $e^+e^- \rightarrow l^+l^-$ + miss.energy events



Multilepton events from “heavy” higgs’ production or from non abelian confined model

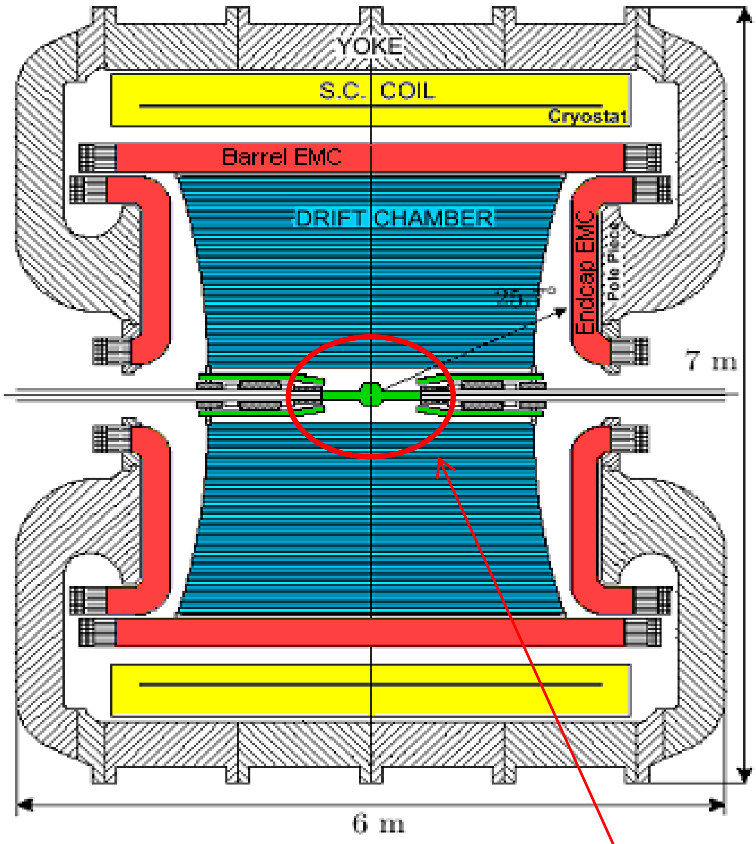
The KLOE experiment at DAΦNE has acquired 2.5 fb^{-1} in the data taking period between 2001 and 2006

Following the success of the run on SIDDHARTA, it is now preparing to roll back on the beam line for a new data taking campaign, under the name of KLOE-2

The new run is expected to start in spring 2010. By mid 2011 some major detector upgrade will be ready for installation (of relevance for the physics discussed in this talk)

What is going to happen after 2012 has not been decided yet. At that point the progress of the SuperB project can become a critical issue

The KLOE detector



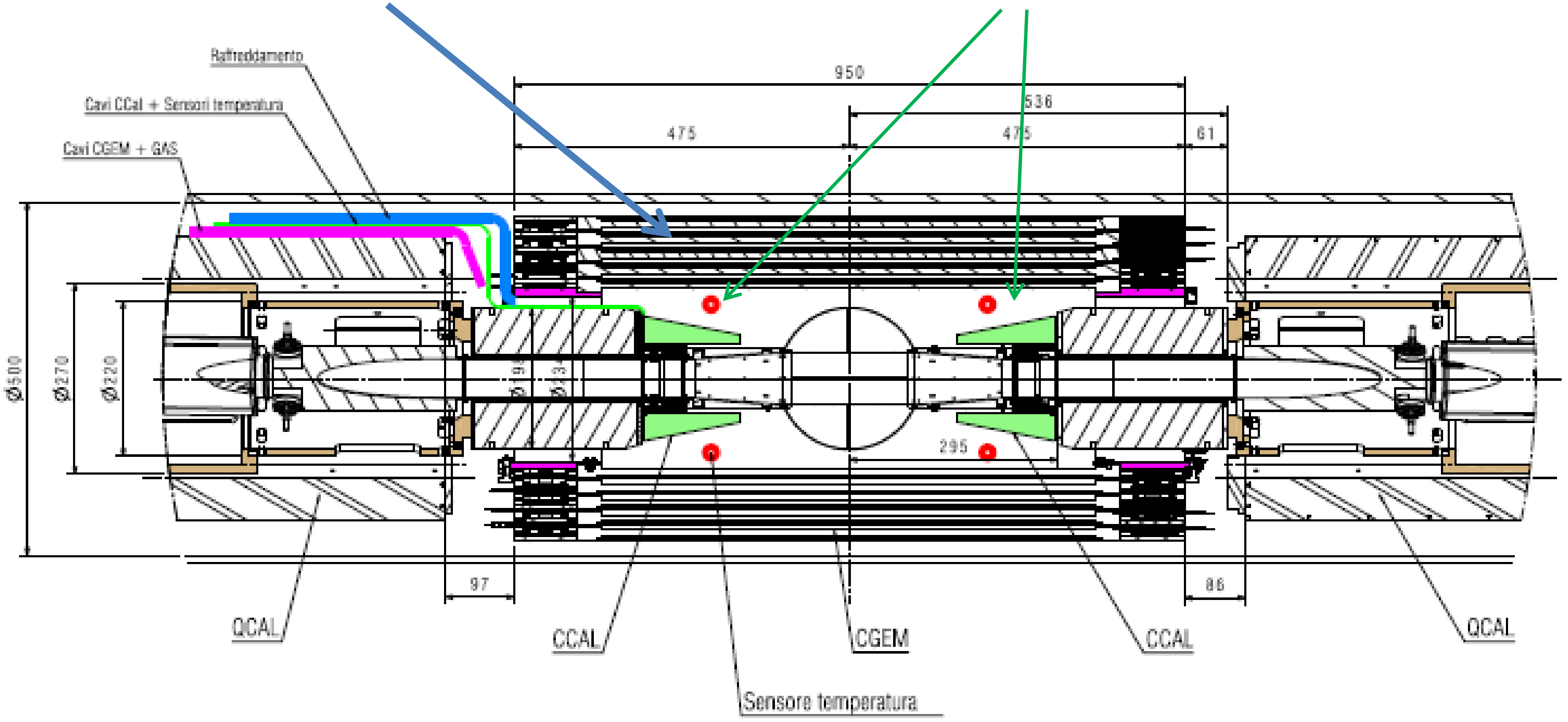
- ❖ **Superconducting coil** $B = 0.52$ T
- ❖**Be beam pipe** (0.5 mm thick), spherical 10 cm radius
- ❖**Electromagnetic calorimeter** Lead/scintillating fibers (1 mm ∅) 4880 PMT's, 15 X_0
- ❖**Drift chamber** (4 m ∅ × 3.3 m) 90% He + 10% IsoB, CF frame, 12582 stereo, single sense wire, "almost squared" cells
- ❖**Quadrupole calorimeter**

Note the empty space of
R ~ 30 cm around the IP

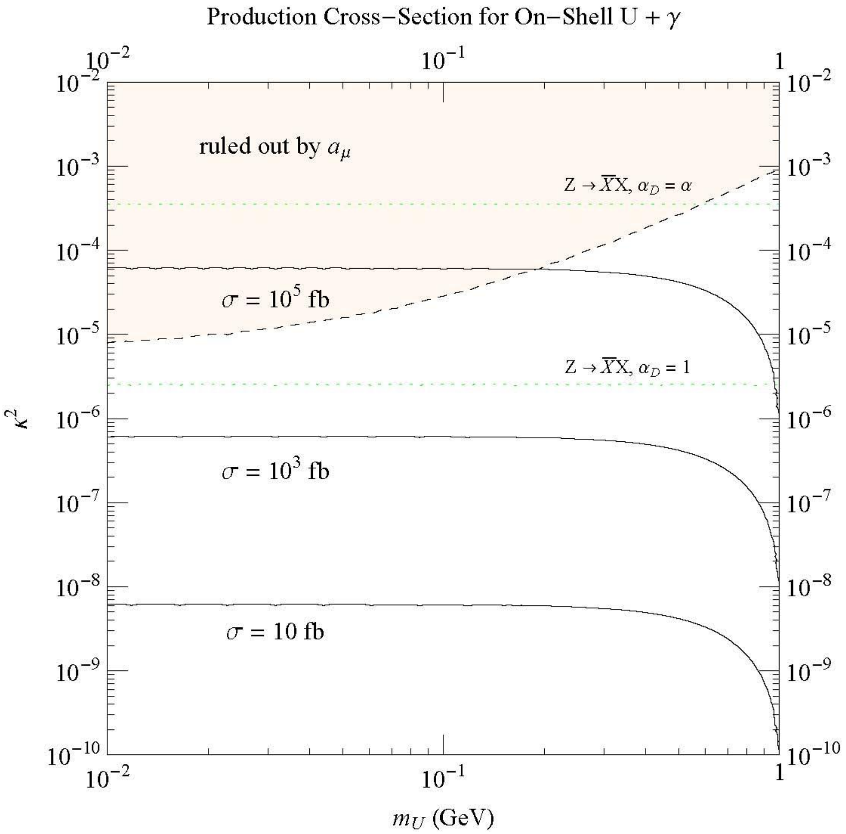
New sub-detectors will be installed around the interaction region

An inner tracker to improve on tracking resolution and acceptance

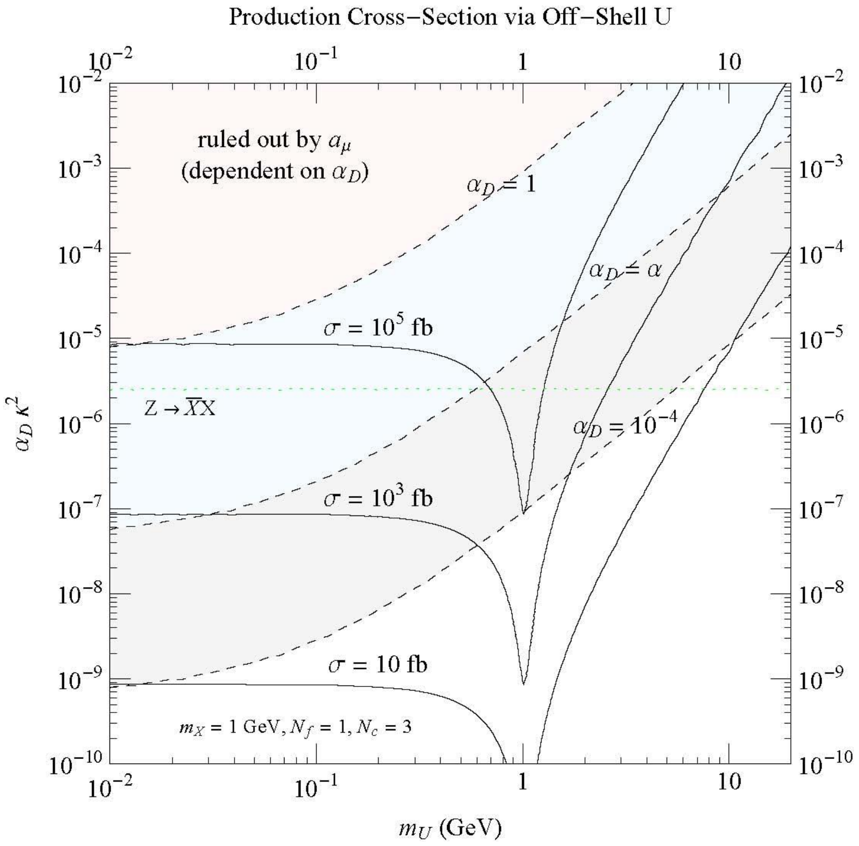
Forward calorimeters to increase acceptance for photons



Dark cross sections at DAΦNE



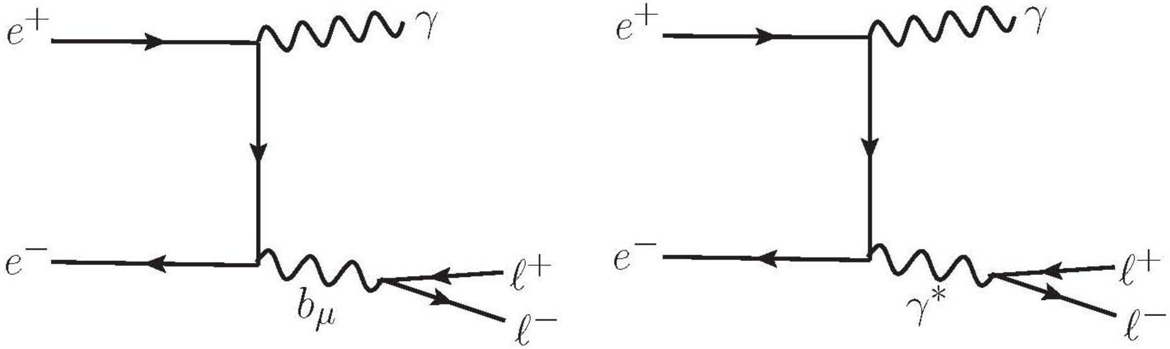
On shell *U* boson production in simple U(1) model



Multilepton events in higher dimension confined model

An *U* boson can be created in the reaction $e^+e^- \rightarrow U\gamma$

It can eventually decay to a lepton pair giving rise to the process $e^+e^- \rightarrow l^+l^-\gamma$



It has to fight with a huge QED background but obviously it has the advantage of being resonant around M_U

A rough estimate of the S/B for this process is:

$$\frac{S}{\sqrt{B}} = \sqrt{\sigma_0 L}\,\frac{\varepsilon^2}{\sqrt{\alpha/\pi}}\sqrt{\frac{M_U}{\delta m}}B(U \to l^+l^-)$$

where σ_0 is the $e^+e^- \to \gamma\gamma$ cross section at the energy of interest and δm is the invariant mass resolution of the experiment

Using KLOE(-2) luminosity/resolution figures the possible reach is $\varepsilon \sim 10^{-3}$

A similar reach is also valid for present day B-factories

BaBar has in fact searched for resonances in Y(2s,3s) → $\mu^+\mu^-\gamma$ events motivated by the existence of possible axion-like particles or of a very light higgs A_0

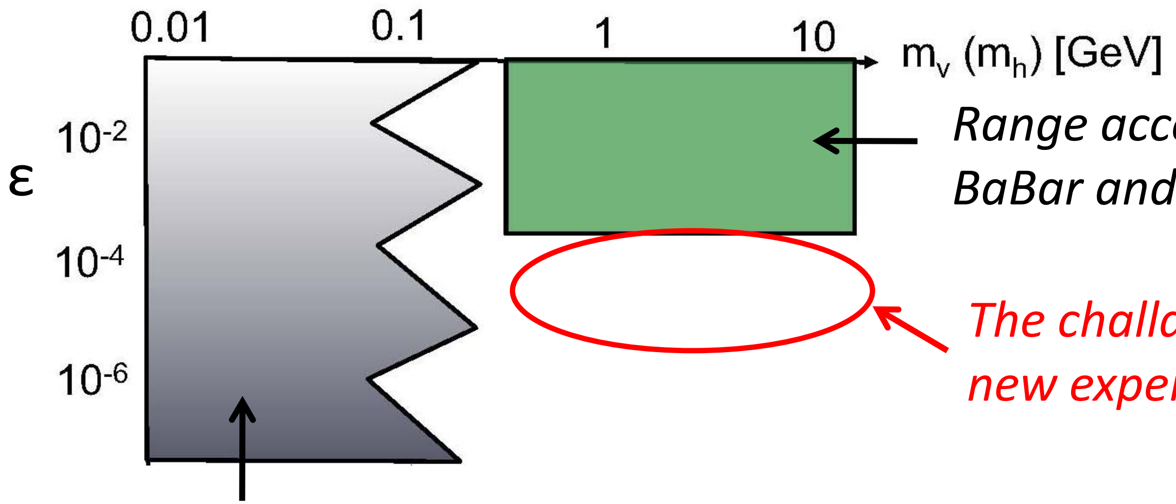
An upper limit on $B(Y \to A_0\gamma \to \mu^+\mu^-\gamma)$ of $\sim 10^{-6}$ has been set down to threshold (*PRL 103, 081803 (2009)*)

The above figure can be translated into a limit on $\varepsilon \sim 10^{-3}$

KLOE can confirm this result and probably study also the $e^+e^-\gamma$ final state which is unavailable at BaBar

As stated before, a search for the *U* boson can be performed also with fixed target experiments. Here the cross sections are even higher, but also backgrounds are

Interestingly enough there is an almost perfect complementarity between the two approaches in terms of available parameters space



Range accessible to BaBar and KLOE

The challange for new experiments!

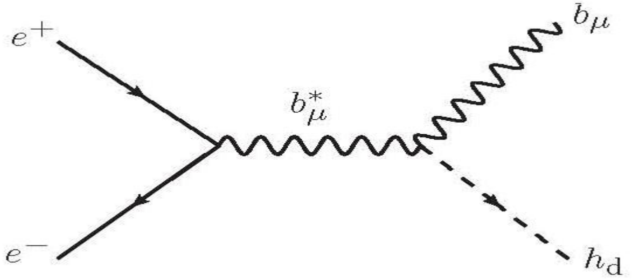
Range accessible to fixed target

Following the above arguments, it is clear that in order to exploit as much as possible the increased luminosity of the new machines the crucial point becomes improving the invariant mass resolution of the detector

Under this respect, the Inner Tracker of KLOE-2 can play a key role. According to the MC simulation, an improvement of a factor ~ 2 is expected for the single track momentum resolution, which should reflect in a similar improvement for the invariant mass. More detailed MC studies are under development

For the same reason, the design of the SuperB detector should aim at the best invariant mass resolution as possible

One of the most interesting mechanisms for dark particles production is the higgs'-strahlung: $e^+e^- \rightarrow U\ h'$, which is dominant if $m_{h'} < m_u$



The cross section for this process scales approximately as:

$$\sigma \approx 20\,fb \times \left(\frac{\alpha}{\alpha_D}\right)\left(\frac{\varepsilon}{10^{-4}}\right)\frac{10GeV}{s}$$

so it can be as large as ~ 1 pb at DAΦNE energies

In the case the *h’* is lighter than the *U* boson, it is relatively long-lived, *O*(10^{-9} s) . It therefore tends to escape detection, giving rise to a lepton pair + missing energy signal

There are several advantages for this type of signature:

1. There is no physics background. The main contamination comes from QED events with a missing photon. Here the ermeticity of KLOE can play an extremely positive role
2. In case of photon losses $P_{miss} = E_{miss}$, which is not the case for massive particles.
3. The angular distribution for the higgs-strahlung is proportional to $\sin^3(\theta)$, which enhances the geometrical acceptance and further suppresses the QED backgrounds

The *U* boson can be observed in mesons decays also

Many of them have radiative decay channels to one photon. Therefore they can decay to a *U* meson with a BR $\sim\varepsilon^2\,BR(\rightarrow\gamma)$

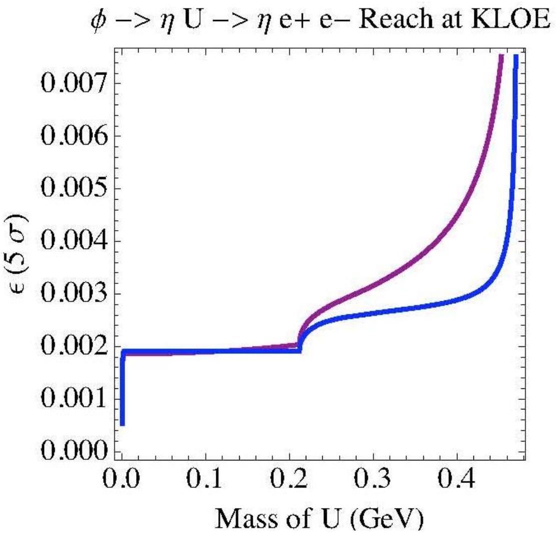
Typically, $BR(\rightarrow\gamma)\sim10^{-2}$ thus one needs $\sim10^{9}$ mesons to reach a sensitivity on $\varepsilon\sim10^{-3}$

At DAΦNE $3\text{x}10^{9}$ Φ mesons are produced every fb^{-1}. The channel to look at is $\Phi\rightarrow\eta U$

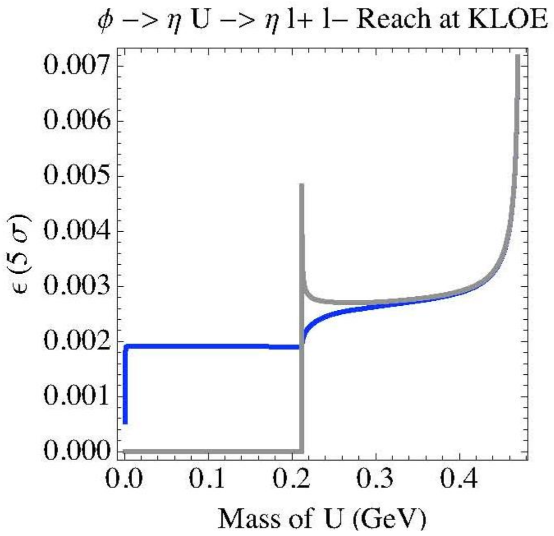
The η meson can be identified through its 3π or γγ decays

A study on the potentials of KLOE, using the present statistics, was done by Reece and Wang (arXiv:0904.1743)

Different lines correspond to different FF parametrizations for the background due to →$\eta\gamma^*\rightarrow\eta l^+l^-$



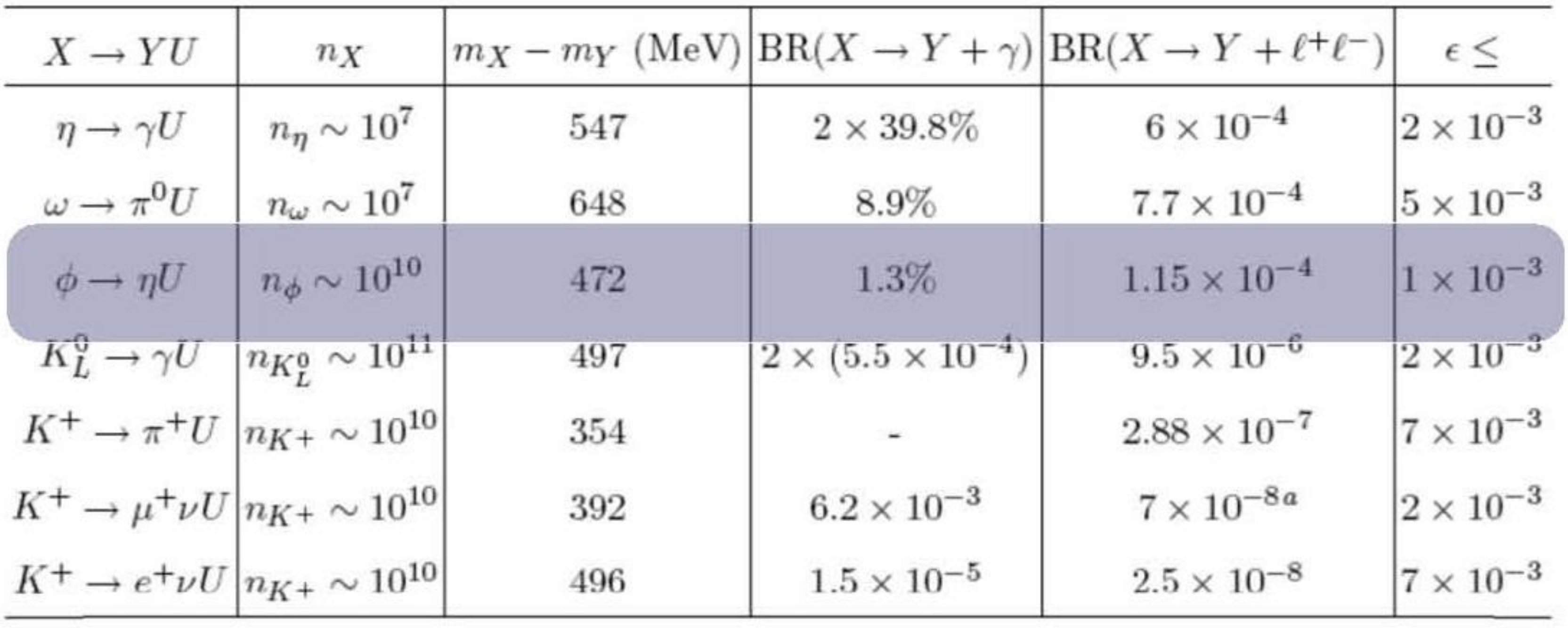
U →e^+e^- only



Including muons

The conclusion of the work is that KLOE(2) can be sensitive to mixing parameters down to $\varepsilon \sim 10^{-3}$

It turns out that among the various meson decays this is in fact the one with the best sensitivity to the dark sector, given the presently available statistical samples. Consider that, even if Wang and Reece did not take into consideration actual detection efficiencies, the available data sample will increase with KLOE-2

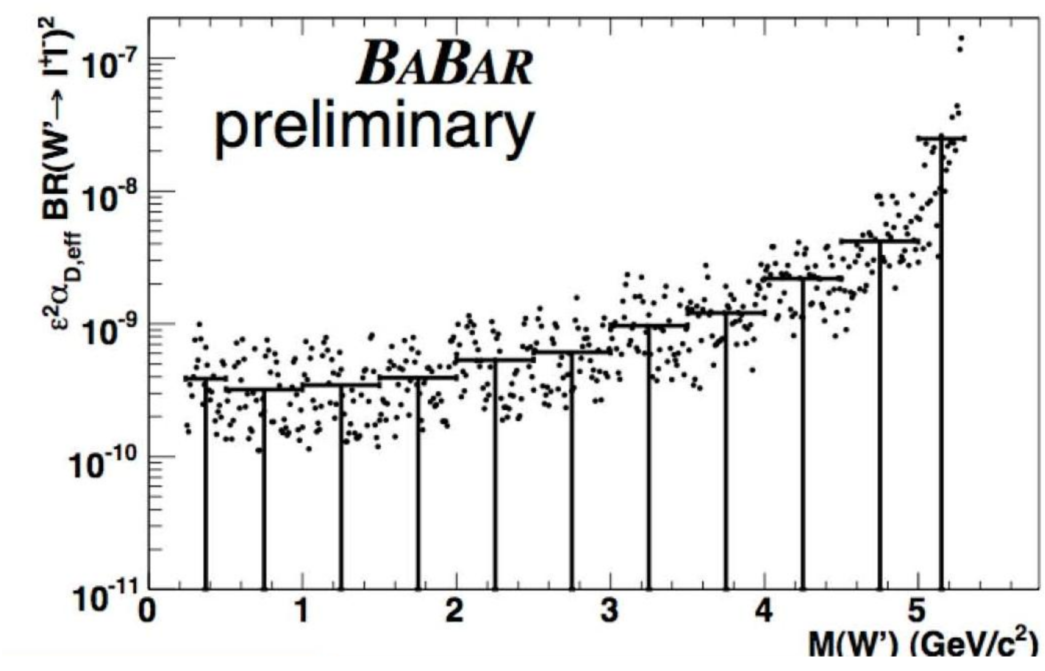


$X \to YU$	n_X	$m_X - m_Y$ (MeV)	$\mathrm{BR}(X \to Y + \gamma)$	$\mathrm{BR}(X \to Y + \ell^+\ell^-)$	$\epsilon \leq$
$\eta \to \gamma U$	$n_\eta \sim 10^7$	547	$2 \times 39.8\%$	6×10^{-4}	2×10^{-3}
$\omega \to \pi^0 U$	$n_\omega \sim 10^7$	648	8.9%	7.7×10^{-4}	5×10^{-3}
$\phi \to \eta U$	$n_\phi \sim 10^{10}$	472	1.3%	1.15×10^{-4}	1×10^{-3}
$K_L^0 \to \gamma U$	$n_{K_L^0} \sim 10^{11}$	497	$2 \times (5.5 \times 10^{-4})$	9.5×10^{-6}	2×10^{-3}
$K^+ \to \pi^+ U$	$n_{K^+} \sim 10^{10}$	354	-	2.88×10^{-7}	7×10^{-3}
$K^+ \to \mu^+ \nu U$	$n_{K^+} \sim 10^{10}$	392	6.2×10^{-3}	7×10^{-8a}	2×10^{-3}
$K^+ \to e^+ \nu U$	$n_{K^+} \sim 10^{10}$	496	1.5×10^{-5}	2.5×10^{-8}	7×10^{-3}

The analysis work by KLOE has just started. News asap.

Probe of the dark sector can be found also in other rare meson decays. These possibilities will be thoroughly discussed by Matt Graham this afternoon, so I will not mention them in my talk

I assume that Matthew will also present the searches of BaBar in the 4 lepton channel (he’s one of the authors of the analysis). This channel can be studied also at KLOE, but it is obviously disfavoured by phase space. At the SuperB, instead, it can be one of the “main courses” in the physics menu



Another potential dark sector signature arises if the *U* boson can decay also to DM particles (or neutrinos as advocated by some authors) resulting 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. BaBar has explicitely taken a few weeks of data with such a kind of trigger, with null results

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

At the SuperB instead this would be again a channel to look for

Concluding

Searches for new physics arising from a low-energy dark sector can be performed at present day or future e^+e^- colliders, as well as at other low-energy facilities

There is quite a number of different possible signatures for which several experiments are required. KLOE-2 and SuperB are in the top list of these experiments

It is my strong belief that KLOE-2, whose activities are starting now and are planned to continue for the next few years, can be a beautiful place in which people interested in these topics can spend part of their time

We have data. We are going to have more. We are ready to open our doors to anybody is willing to contribute. It can be a nice way to enter the Frascati laboratory life, doing some exciting physics analysis