Physics with the KLOE2 experiment at DAΦNE

- **Machine and detector upgrade**
- **CKM precision measurements**
- **Interferometry**
- **Dark matter seach**

KLOE-2 at upgraded DAΦNE

Upgrade of DAΦNE in luminosity:

Crabbed waist scheme at DAΦNE (proposal by P. Raimondi)

- increase L by a factor *O*(5)
- requires minor modifications
- relatively low cost

- Successful experimental test at DAΦNE

KLOE-2 Plan:

- phase 0: KLOE restart taking data end 2009 with a minimal upgrade (L~5 fb^{-1})
- phase 1: full KLOE upgrade (KLOE-2) > 2011 (L>20 fb^{-1})

Physics issues:

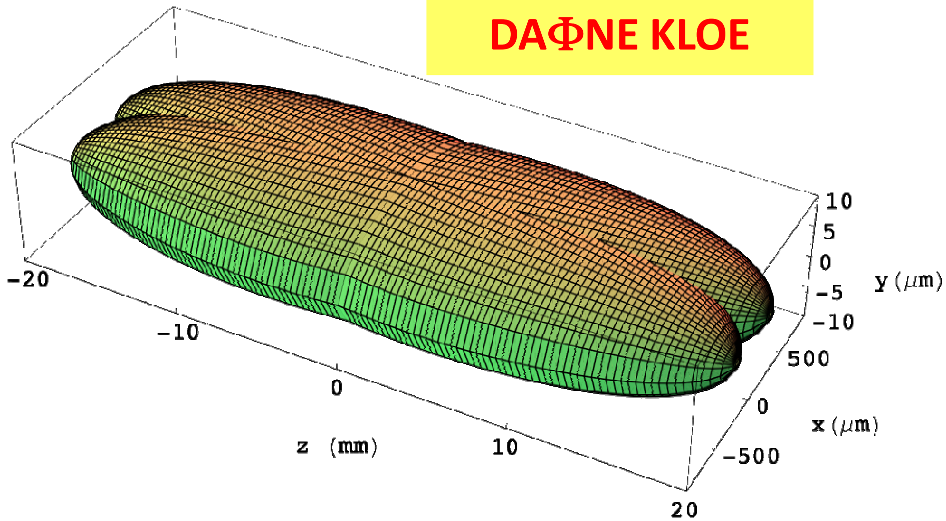
- Neutral kaon interferometry, CPT symmetry & QM tests
- Kaon physics, CKM, LFV, rare K_S decays
- Dark matter
- η,η' physics
- Light scalars, γγ physics
- Hadron cross section at low energy, muon anomaly

Detector upgrade issues:

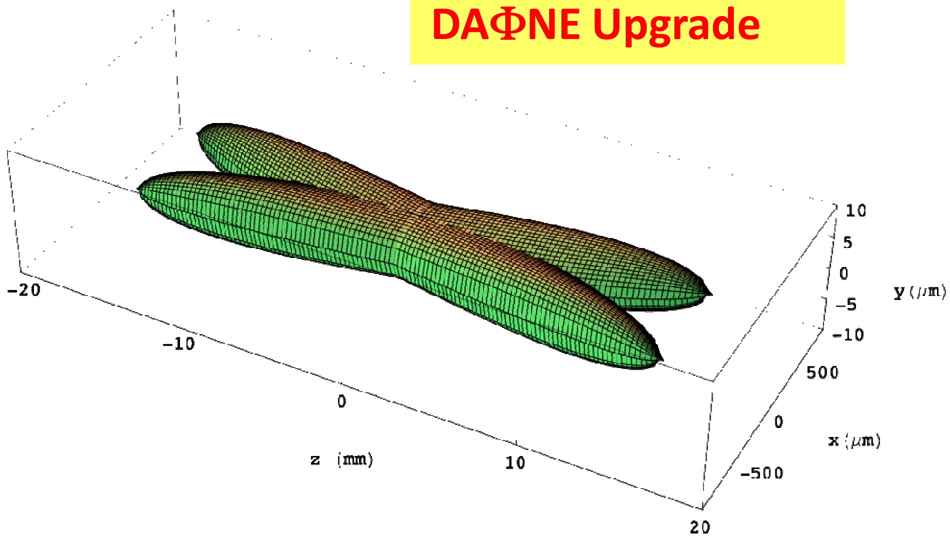
- Inner tracker R&D
- γγ tagging system
- FEE maintenance and upgrade
- Computing and networking update
- etc.. (Trigger, software, …)

DAΦNE Beam distributions @ IP

DAΦNE KLOE



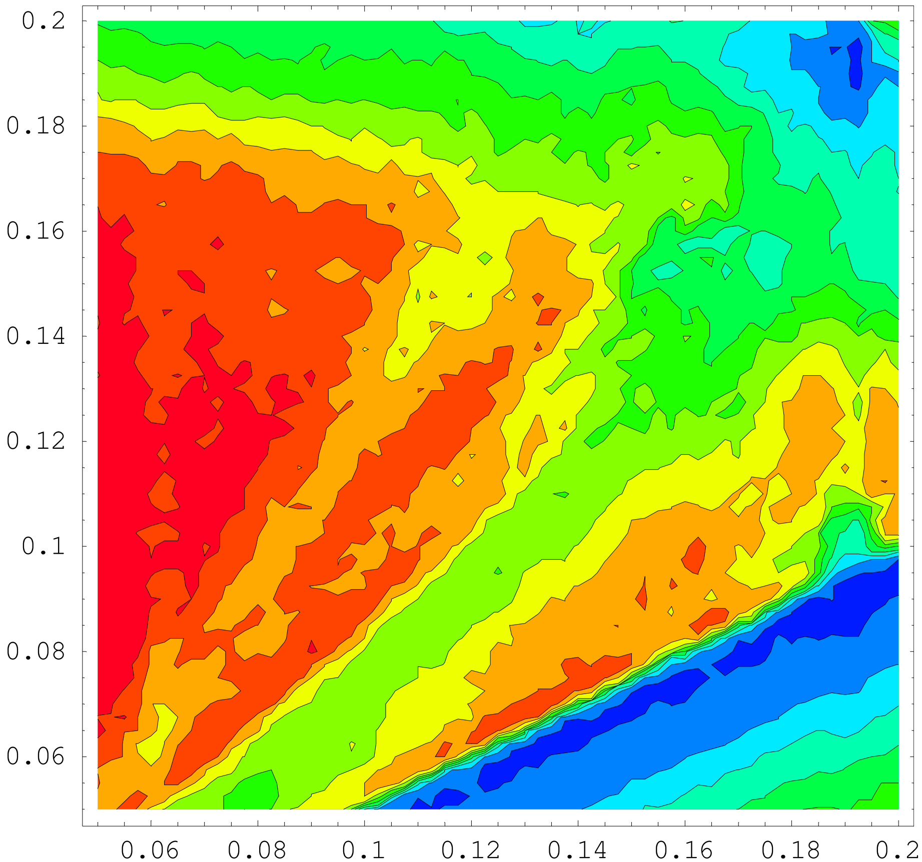
DAΦNE Upgrade



	DAΦNE KLOE	DAΦNE Upgrade
I_{bunch} (mA)	13	13
N_{bunch}	110	110
β_y^* (cm)	1.7	0.65
β_x^* (cm)	170	20
σ_y^* (μm)	7	2.6
σ_x^* (mm)	0.7	0.2
σ_z (mm)	25	20
$\theta_{cross}/2$ (mrad)	12.5	25
$\Phi_{Piwinski}$	0.45	2.5
L ($cm^{-2}s^{-1}$) x10^{32}	1.5	>5

Luminosity vs tunes scan

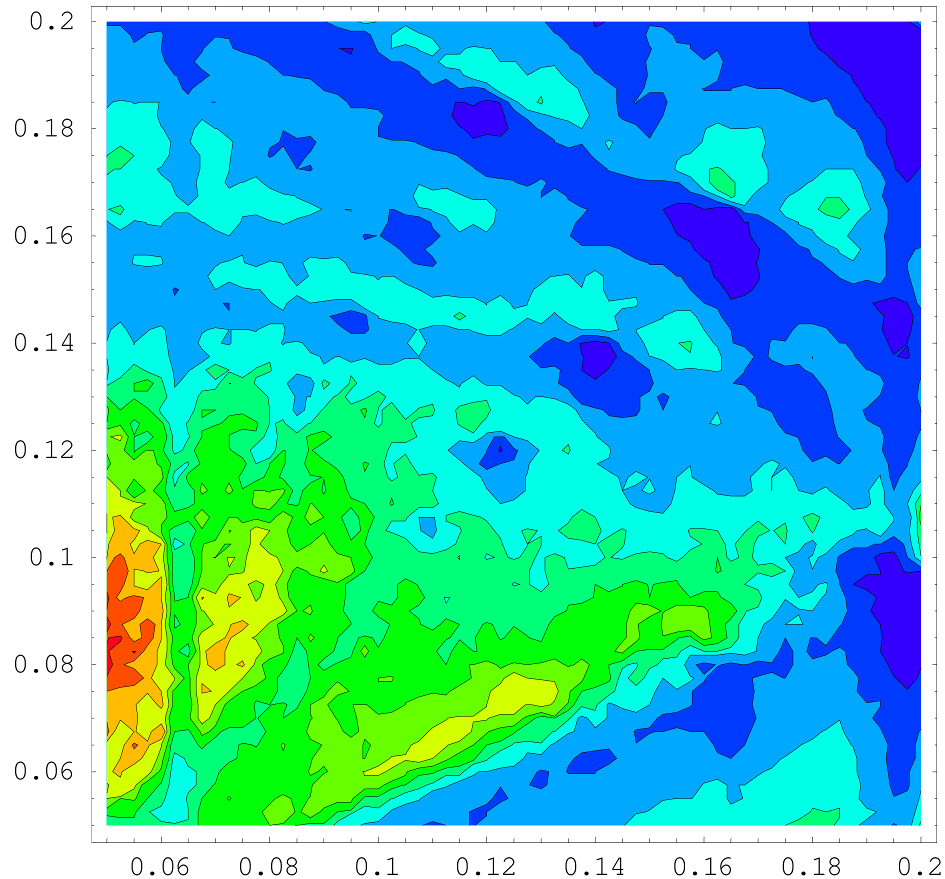
Crab On → 0.6/θ



L_{max} = 2.97x10^{33} cm^{-2}s^{-1}

L_{min} = 2.52x10^{32} cm^{-2}s^{-1}

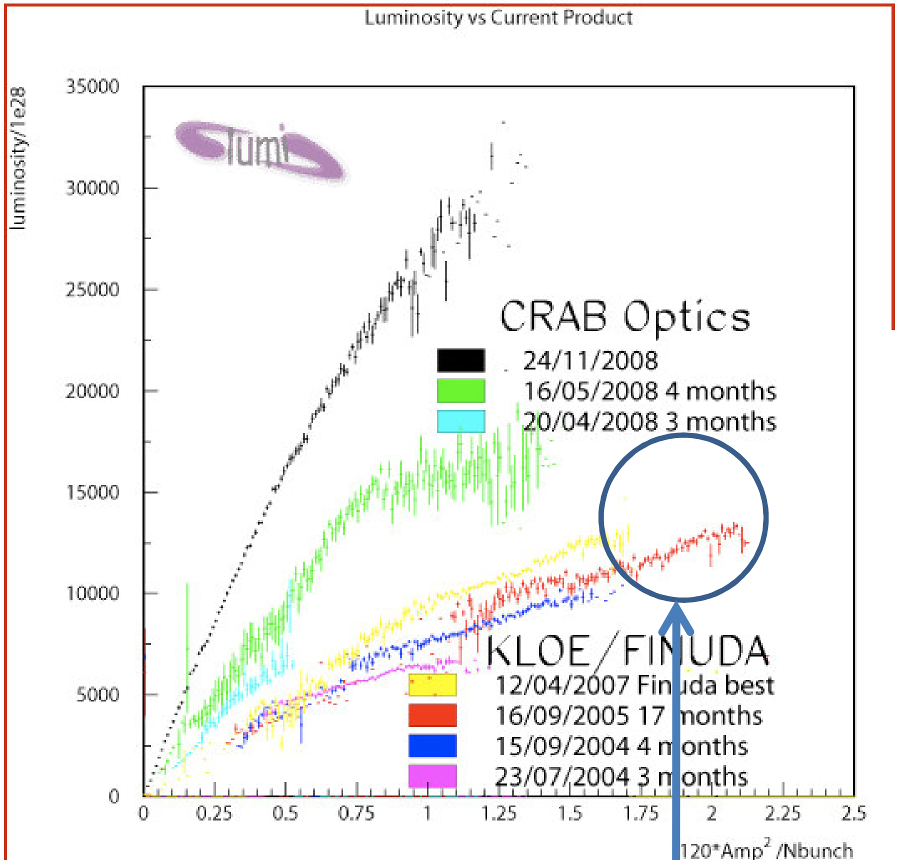
Crab Off



L_{max} = 1.74x10^{33} cm^{-2}s^{-1}

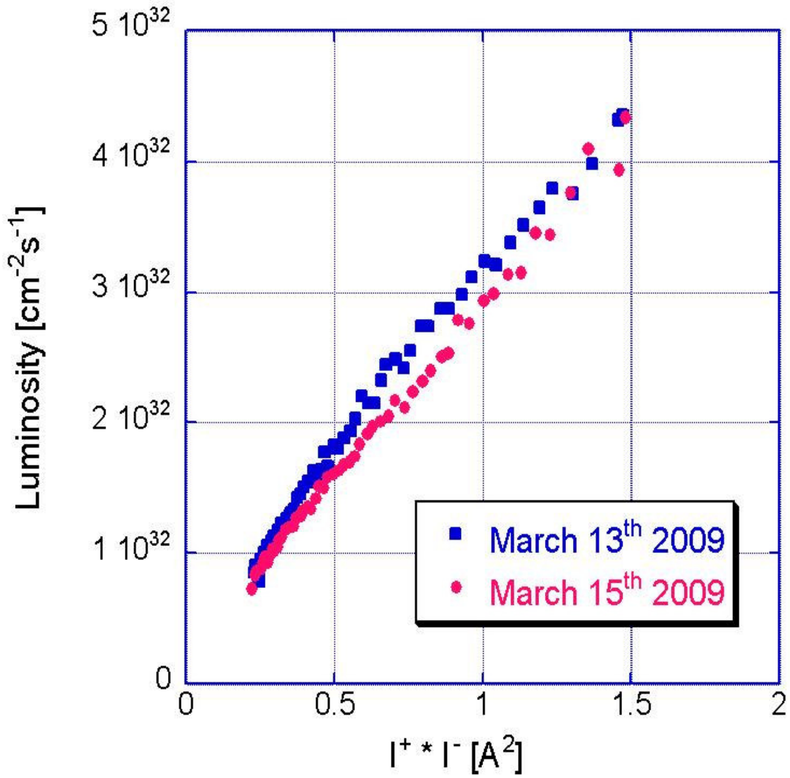
L_{min} = 2.78x10^{31} cm^{-2}s^{-1}

DAΦNE Luminosity versus colliding currents

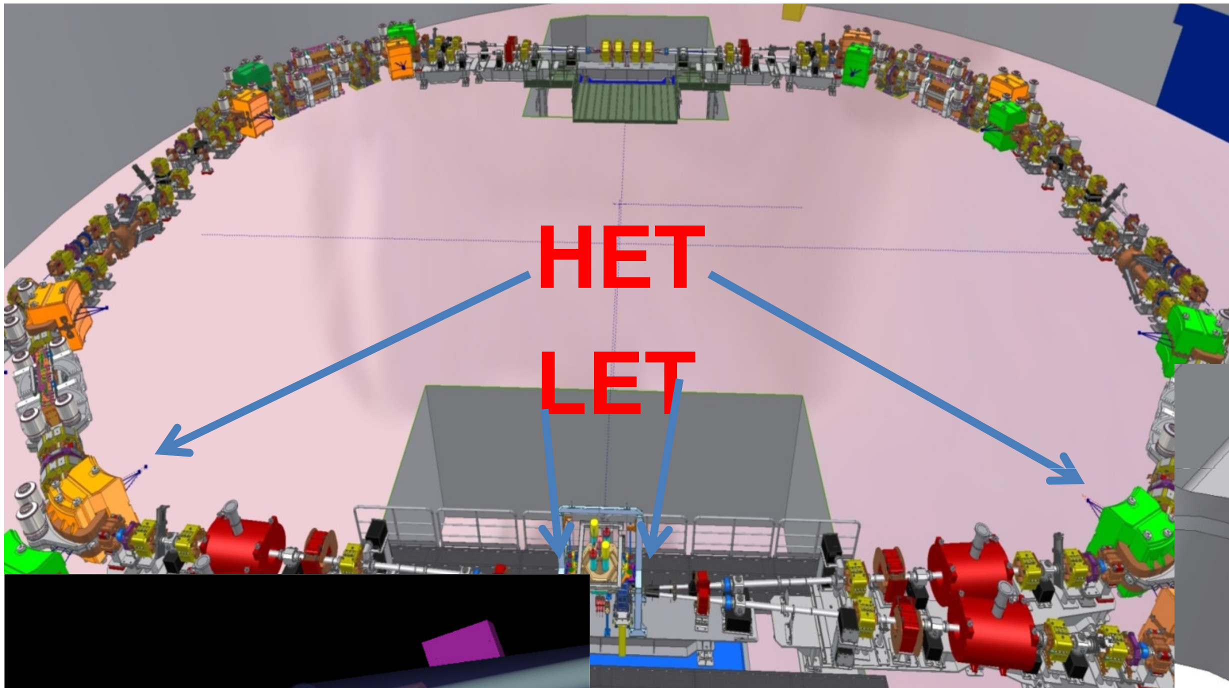


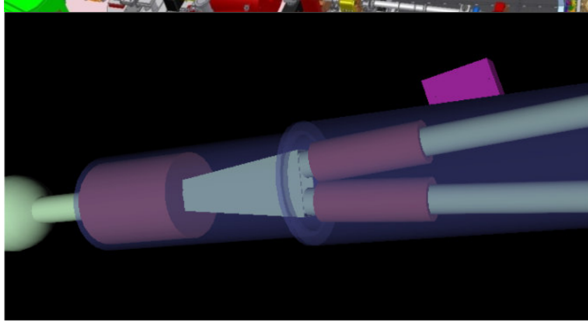
original collision scheme

NEW COLLISION SCHEME:
Large Piwinski angle
Crab-Waist compensation SXTs



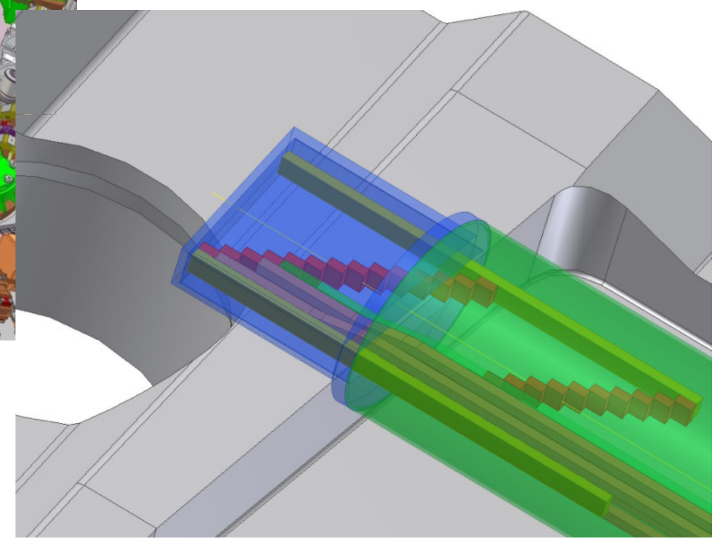
γγ taggers





The HET detector consists in a position detector with a pitch of few millimeter (¾$_E$ ~ 0.6 MeV/mm). The characteristics of this detector are the following:

- Good time resolution to disentangle each bunch (~2.7 ns bunch spacing);
- Capability to acquire data at a frequency of 368 MHz in order to permit event

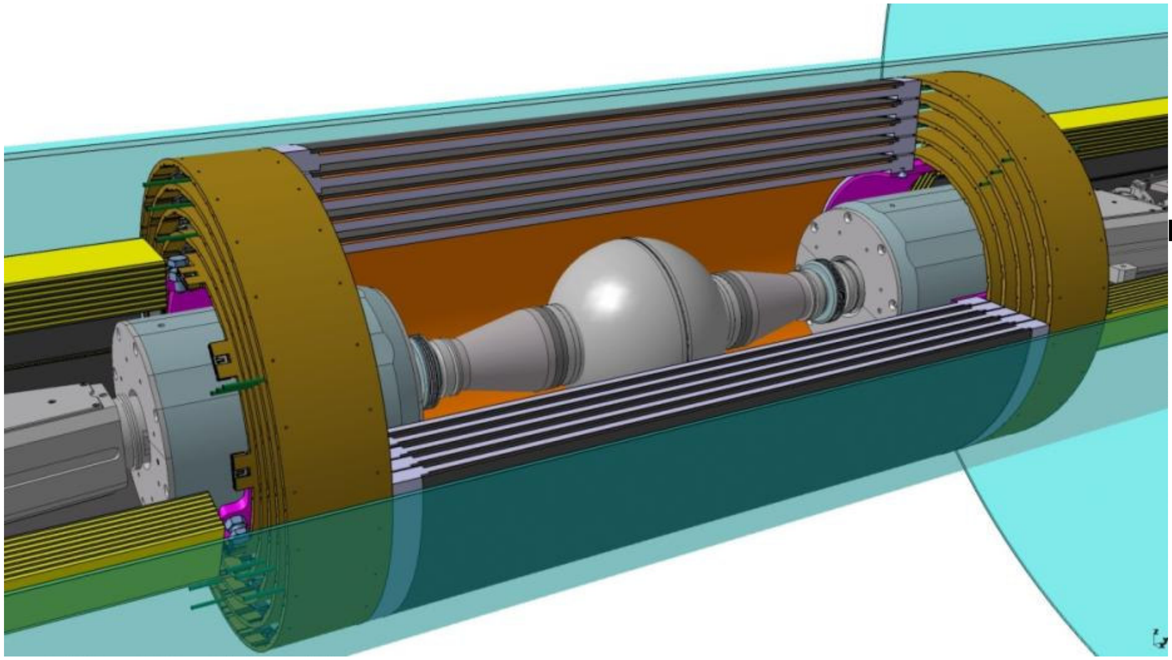


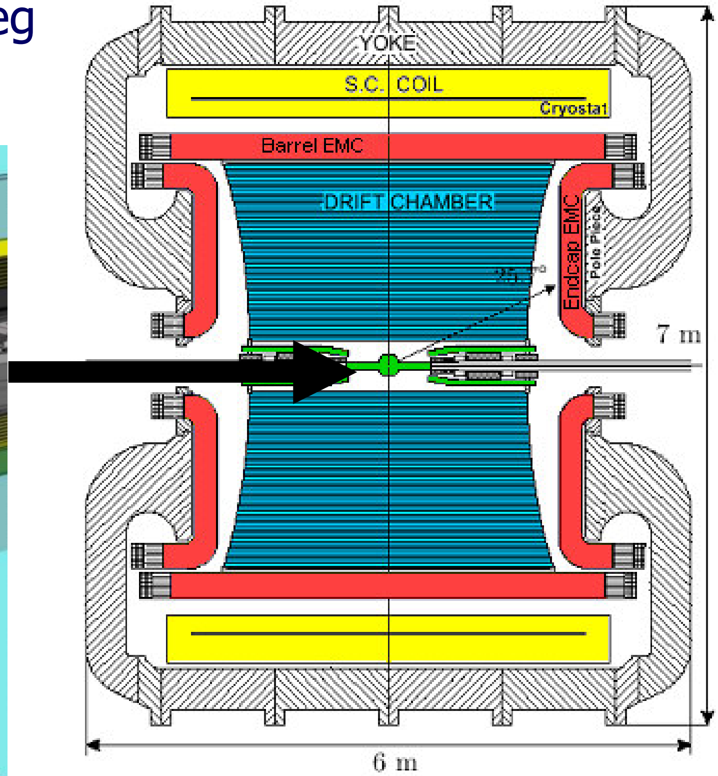
The LET detector consists of a calorimeter capable of detecting electrons and positrons within a wide energy range peaked around 200 MeV. The environmental conditions require radiation-tolerant devices, insensitive to magnetic fields. The physical requirements are the following:

- Good energy resolution to improve the reconstruction of the γγ invariant mass from the decay products;
- Good time resolution to associate detected events with the proper bunch crossing;
- Small size.

Inner tracker at KLOE

- 5 independent tracking layers for a fine vertex reconstruction of K_S and η
- 200 μm $\sigma_{r\varphi}$ and 500 μm σ_Z spatial resolutions with XV readout
- 700 mm active length
- from 150 to 250 mm radii
- 1.8% X_0 total radiation length in the active reg
- _Realized with **Cylindrical-GEM** detectors





Kaon physics

- Set bounds on New Physics from Lepton-Quark Universality
- Precise determination of V_{us}
- Test of Lepton universality Ke3 vs Kμ3
- Most precise test of CKM unitarity

New Physics extensions of the SM can break gauge universality in the form of tree or loop level contributions to muon decays and/or semileptonic processes.

i. *Exotic Muon Decays*: would contribute to the muon lifetime

$$|\mathbf{V_{ud}}|^2 + |\mathbf{V_{us}}|^2 + |\mathbf{V_{ub}}|^2 = 1 - \mathbf{BR(exotic\ \ muon\ \ decays)}$$

Provides best limit on $\mathbf{BR}(\mu^+ \to e^+ \overline{\nu}_e \nu_\mu)$ *~10 better than direct search*

ii. *Additional Z' Gauge Bosons*, contributing at loop level to muons and semileptonic decays differently (*Competitive with direct search*) [PRD 35 (1987)]

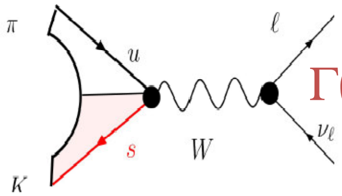
iii. SUSY particle loops affecting muon and semileptonic decays differently: constraints on *slepton-squark mass difference* (x*2-3 precision needed*)

[PRL 75 (1995) , PRL 88 (2002)]

Present accuracy set bounds on the scale of New Physics Λ_{NP} at 1-2 TeV

$$|\mathbf{V_{ud}}|^2 + |\mathbf{V_{us}}|^2 + |\mathbf{V_{ub}}|^2 = 1 + \varepsilon_{\mathbf{NP}} \qquad \varepsilon_{\mathbf{NP}} \approx \mathbf{M_W^2/\Lambda_{NP}^2}$$

Vus, lepton universality and CKM unitarity at KLOE

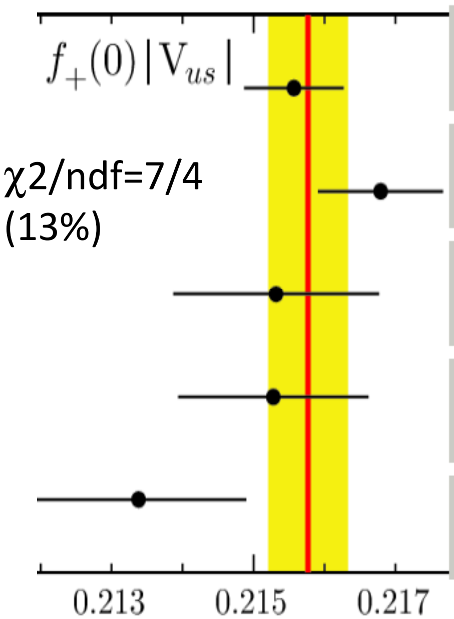


$$\Gamma(K \to \pi l \nu(\gamma)) \propto |V_{us}|^2 \, |f_+^{K\pi}(0)|^2 \, I^l_K(\lambda_+, \lambda_0, 0)\,(1 + \delta^l_K)$$

All KLOE exp. inputs but K_S lifetime

KLOE average @ *0.28%*
$|V_{us}| f_+(0) = 0.2157(6)$

$K_{\ell 3}$: $K \to \pi \ell \nu$

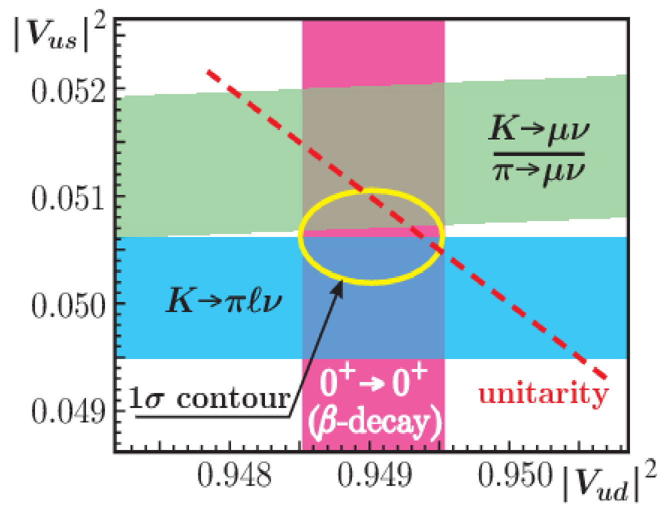


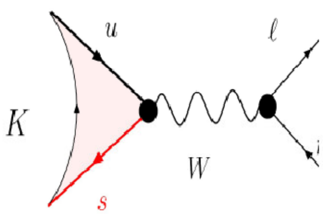
		err %
K_Le3	0.2155(7)	0.3
$K_L\mu3$	0.2167(9)	0.4
K_Se3	0.2152(14)	0.7
$K^\pm e3$	0.2152(13)	0.6
$K^\pm\mu3$	0.2132(15)	0.7

$|V_{us}| = 0.2237(13)$ 0.6%

$$r_{\mu e} = \frac{|f_+(0)\, V_{us}|^2_{\mu 3,\ \mathrm{exp}}}{|f_+(0)\, V_{us}|^2_{e3,\ \mathrm{exp}}}$$

$r_{\mu e} = 1.000(8)$





$K_{\ell 2}$: $K \to \ell \nu$

$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} \propto \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K^2}{f_\pi^2}$$

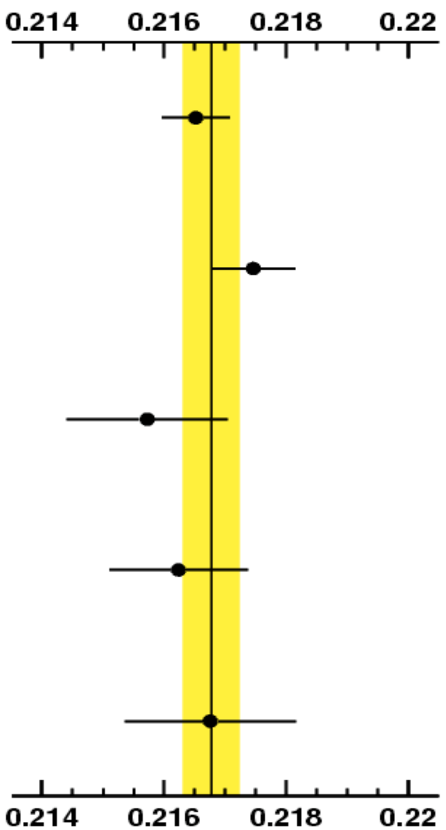
$|V_{us}/V_{ud}| = 0.2323(15)$

$1 - |V_{ud}|^2 - |V_{us}|^2 = 4(7) \times 10^{-4}$ @0.6σ

World Average: 6×10^{-4} accuracy

$|V_{us}|f_+(0)$ present world average (WA)

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+^{K^0\pi^-}(0)|^2 I_{K\ell}(\lambda_{+,0}) (1+\delta^K_{SU(2)}+\delta^{K\ell}_{em})^2$$



		% err	BR	τ	δ	$I_{K\ell}$
K_Le3	**0.21652(56)**	**0.25**	0.11	**0.20**	0.11	0.10
$K_L\mu3$	**0.21746(69)**	**0.32**	0.17	**0.19**	0.11	0.15
K_Se3	**0.21572(132)**	**0.61**	**0.60**	0.03	0.11	0.10
$K^{+/-}e3$	**0.21624(113)**	**0.52**	**0.31**	0.06	**0.41**	0.09
$K^{+/-}\mu3$	**0.21676(141)**	**0.65**	**0.48**	0.06	**0.41**	0.15

can be improved

Average: $|V_{us}| f(0)$ = 0.21660(47) χ^2/ndf 3.03/4 (55%)

$|V_{us}| f_+(0)$: KLOE+Step0+WA

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+^{K^0\pi^-}(0)|^2 I_{K\ell}(\lambda_{+,0}) (1+\delta^K_{SU(2)}+\delta^{K\ell}_{em})^2$$

Approx. contr. to % err from:

		% err	BR	τ	δ	$I_{K\ell}$
$K_L e3$	0.2155(4)	0.21	0.09	**0.13**	**0.11**	0.09
$K_L \mu3$	0.2167(5)	0.25	0.10	**0.13**	**0.11**	0.15
$K_S e3$	0.2153(7)	0.33	**0.30**	0.03	**0.11**	0.09
$K^\pm e3$	0.2152(8)	0.38	**0.25**	0.12	**0.25**	0.09
$K^\pm \mu3$	0.2132(9)	0.42	**0.27**	0.12	**0.25**	0.15

Fractional error on $|V_{us}| f_+(0)$ is 0.14%

World Average is 0.23%

Universality: KLOE+Step0+WA

- Today with $f_+(0)$ @ 0.5% the accuracy on the unitarity relation of the first row is

$$\sigma\,(1-V_{ud}^{\,2}-V_{us}^{\,2}) = 6\times10^{-4}$$

- $f_+(0)$ @ 0.1% accuracy from lattice within few years

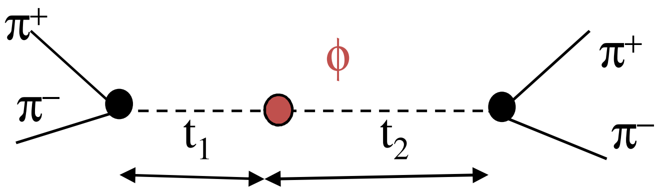
	$f_+(0)V_{us}$	V_{us}
KLOE today *(World Average)*	**0.28%** (0.23%)	**0.30%** (0.25%)
KLOE + Step0 + WA	**0.14%**	**0.17%**

- With $|V_{ud}|$ @ 0.02% and $|V_{us}|$ @0.17% the accuracy on the unitarity relation of the first row would improve by a factor of ~2

$$\sigma\,(1-V_{ud}^{\,2}-V_{us}^{\,2}) = (3\div4)\times10^{-4}$$

Neutral kaon interferometry

$$|i\rangle = \frac{1}{\sqrt{2}}\left[|K^0\rangle|\overline{K}^0\rangle - |\overline{K}^0\rangle|K^0\rangle\right]$$

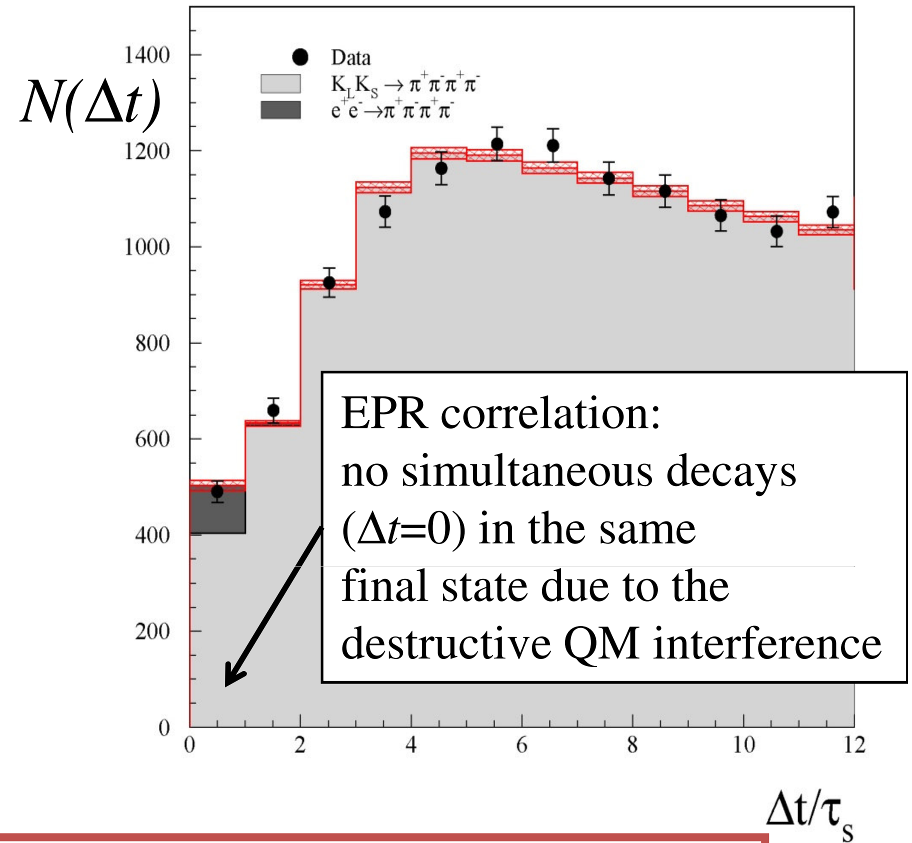


$\Delta t = |t_1 - t_2|$

Most precise test of quantum coherence in an entangled system:

$$\zeta_{0\bar{0}} = (1.4 \pm 9.5_{STAT} \pm 3.8_{SYST}) \times 10^{-7}$$

ζ decoherence parameter (QM predicts ζ=0)



Quantum gravity effects might induce:

1) decoherence and CPT violation
(at most $\gamma = O(m_K^2/M_{Planck})$~$2\times10^{-20}$ GeV)

$$\gamma = (0.7 \pm 1.2_{STAT} \pm 0.3_{SYST}) \times 10^{-21}\ \text{GeV}$$

2) modification of the initial correlation of the kaon pair
(at most $\omega = O(m_K^2/M_{Planck}/\Delta\Gamma)$ ~1×10^{-3}

$$|i\rangle \propto (K^0\overline{K}^0 - K^0\overline{K}^0) + \omega(K^0\overline{K}^0 + K^0\overline{K}^0)$$

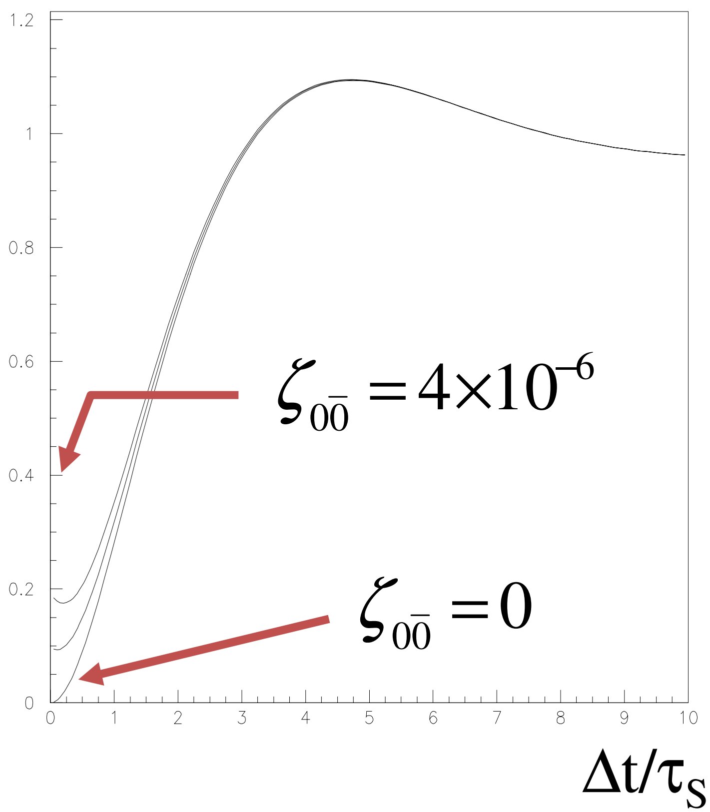
$$\Re\omega = (-1.6^{+3.0}_{-2.1\,STAT} \pm 0.4_{SYST}) \times 10^{-4}$$

$$\Im\omega = (-1.7^{+3.3}_{-3.0\,STAT} \pm 1.2_{SYST}) \times 10^{-4}$$

Interferometry at KLOE-2: $\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^- \pi^+\pi^-$

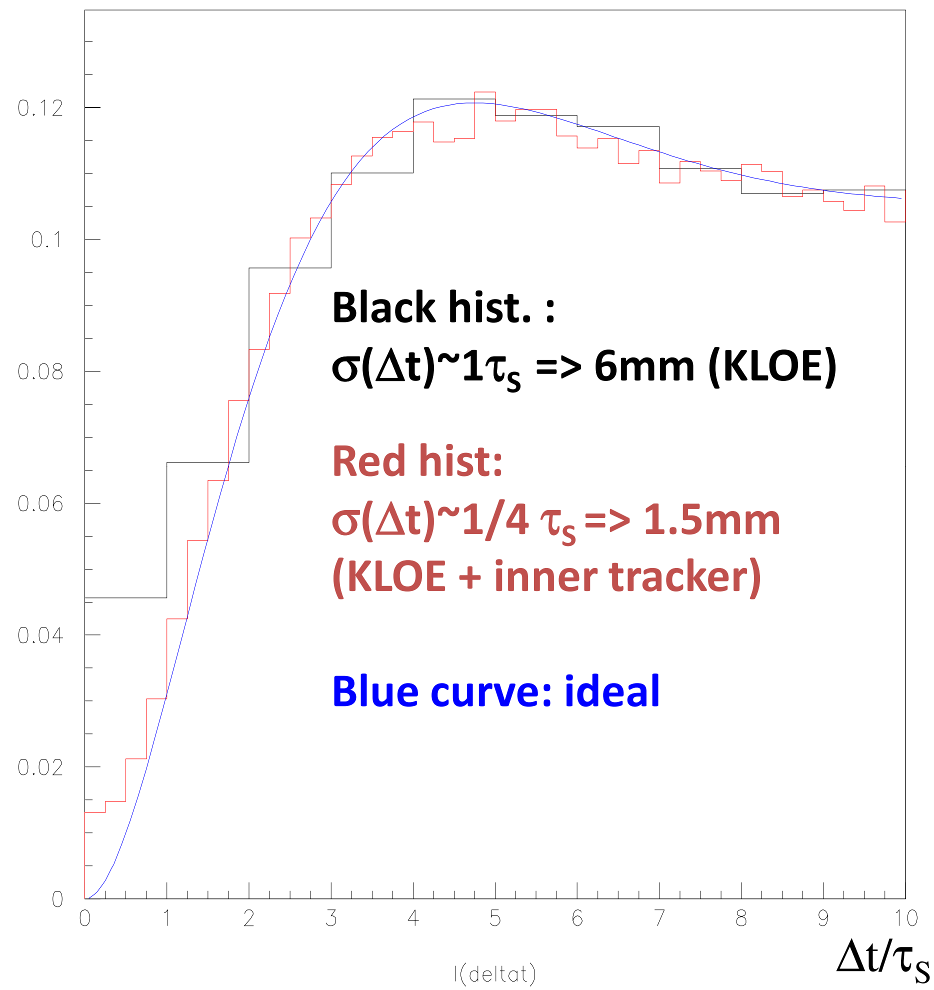
Possible signal of decoherence concentrated at very small Δt

$I(\pi^+\pi^-, \pi^+\pi^-;\Delta t)$ (a.u.)



Theoretical distribution

$I(\pi^+\pi^-, \pi^+\pi^-;\Delta t)$ (a.u.)



Reconstructed distribution (MC)

Perspectives with KLOE-2 at upgraded DAΦNE

Mode	Test of	Param.	Present best published measurement	KLOE-2 $L=50\ fb^{-1}$
$K_S \to \pi e \nu$	CP, CPT	A_S	$(1.5 \pm 11) \times 10^{-3}$	$\pm 1 \times 10^{-3}$
$\pi^+\pi^-$ $\pi e \nu$	CP, CPT	A_L	$(3322 \pm 58 \pm 47) \times 10^{-6}$	$\pm 25 \times 10^{-6}$
$\pi^+\pi^-$ $\pi^0\pi^0$	CP	$Re(\varepsilon'/\varepsilon)$	$(1.65 \pm 0.26) \times 10^{-3}$ (*)	$\pm 0.2 \times 10^{-3}$
$\pi^+\pi^-$ $\pi^0\pi^0$	CP, CPT	$Im(\varepsilon'/\varepsilon)$	$(-1.2 \pm 2.3) \times 10^{-3}$ (*)	$\pm 3 \times 10^{-3}$
$\pi e \nu$ $\pi e \nu$	CPT	$Re(\delta)+Re(x_-)$	$Re(\delta) = (0.25 \pm 0.23) \times 10^{-3}$ (*) $Re(x_-) = (-4.2 \pm 1.7) \times 10^{-3}$ (*)	$\pm 0.2 \times 10^{-3}$
$\pi e \nu$ $\pi e \nu$	CPT	$Im(\delta)+Im(x_+)$	$Im(\delta) = (-0.6 \pm 1.9) \times 10^{-5}$ (*) $Im(x_+) = (0.2 \pm 2.2) \times 10^{-3}$ (*)	$\pm 3 \times 10^{-3}$
$\pi^+\pi^-$ $\pi^+\pi^-$		Δm	$(5.288 \pm 0.043) \times 10^9\ s^{-1}$	$\pm 0.03 \times 10^9\ s^{-1}$

(*) = PDG 2008 fit

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Perspectives with KLOE-2 at upgraded DAΦNE

Mode	Test of	Param.	Present best published measurement	KLOE-2 $L=50\ fb^{-1}$
$\pi^+\pi^-$ $\pi^+\pi^-$	QM	ζ_{00}	$(1.0 \pm 2.1) \times 10^{-6}$	$\pm 0.1 \times 10^{-6}$
$\pi^+\pi^-$ $\pi^+\pi^-$	QM	ζ_{SL}	$(1.8 \pm 4.1) \times 10^{-2}$	$\pm 0.2 \times 10^{-2}$
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & QM	α	$(-0.5 \pm 2.8) \times 10^{-17}$ GeV	$\pm 2 \times 10^{-17}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & QM	β	$(2.5 \pm 2.3) \times 10^{-19}$ GeV	$\pm 0.1 \times 10^{-19}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & QM	γ	$(1.1 \pm 2.5) \times 10^{-21}$ GeV	$\pm 0.2 \times 10^{-21}$ GeV compl. pos. hyp. $\pm 0.1 \times 10^{-21}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & EPR corr.	Re(ω)	$(1.1 \pm 7.0) \times 10^{-4}$	$\pm 2 \times 10^{-5}$
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & EPR corr.	Im(ω)	$(3.4 \pm 4.9) \times 10^{-4}$	$\pm 2 \times 10^{-5}$
$K_{S,L} \to \pi e \nu$	CPT & Lorentz	Δa_0	$[(0.4 \pm 1.8) \times 10^{-17}$ GeV]	$\pm 2 \times 10^{-18}$ GeV
$\pi^+\pi^-$ $\pi^+\pi^-$	CPT & Lorentz	Δa_Z	$[(2.4 \pm 9.7) \times 10^{-18}$ GeV]	$\pm 7 \times 10^{-19}$ GeV
$\pi^+\pi^-$ $\pi e \nu$	CPT & Lorentz	$\Delta a_{X,Y}$	[$<10^{-21}$ GeV]	$\pm 4 \times 10^{-19}$ GeV

Dark Matter Perspective searches

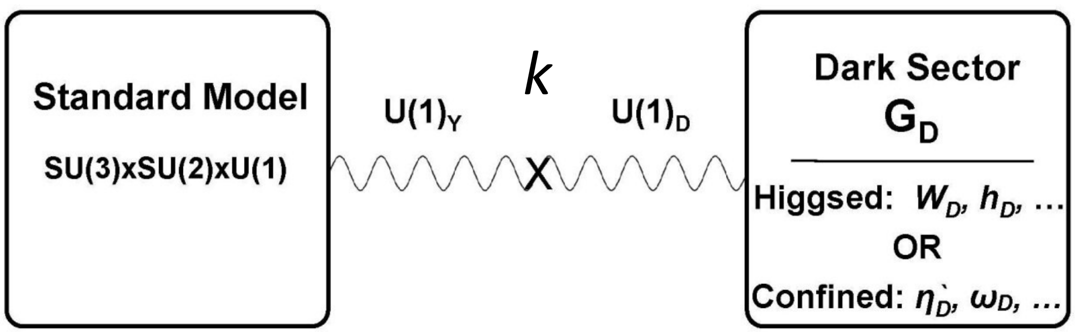
Several recent puzzling astrophysical observations (PAMELA, ATIC, INTEGRAL, DAMA) can be interpreted by postulating the existence of some secluded gauge sector with a rich phenomenology at low (O(1 GeV)) energies.
Some basic papers on the issue are:

1. C. Boehm, P. Fayet: Nucl. Phys. B (2004) 219-263
2. N. Borodatchenkova et al. : Phys. Rev. Lett. 96 (2006) 141802
3. M. Pospelov: arXiv:0811.1030
4. N. Arkani-Hamed et al.: arXiv:0810.0713
5. B. Batell et al.: arXiv:0903.0363
6. R. Essig et al.: arXiv:0903.3941

Hidden valley model

These models postulate a hidden valley, well separated from the world with which they only occasionally get in touch

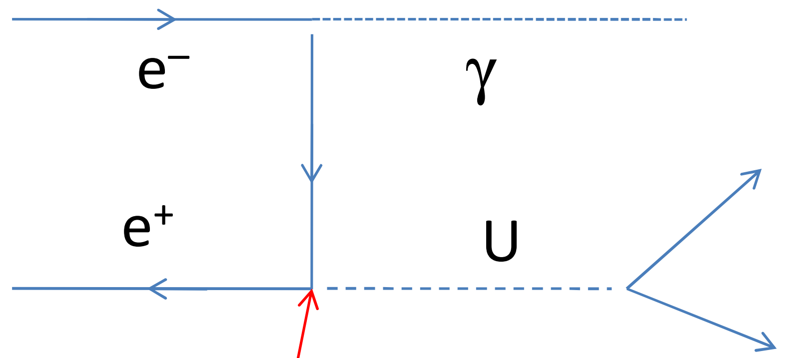
Here, the secluded particles mix with the Standard Model ones through some mechanism with mixing parameter *k* of order up to $10^{-2} - 10^{-3}$ Interestingly enough much lower values for *k* are disfavoured by cosmological consideration



(from reference 6)

T channel production

The U boson can be observed through the radiative process: $e^+e^- \rightarrow Ug \rightarrow l^+l^-$ (l=e,m)

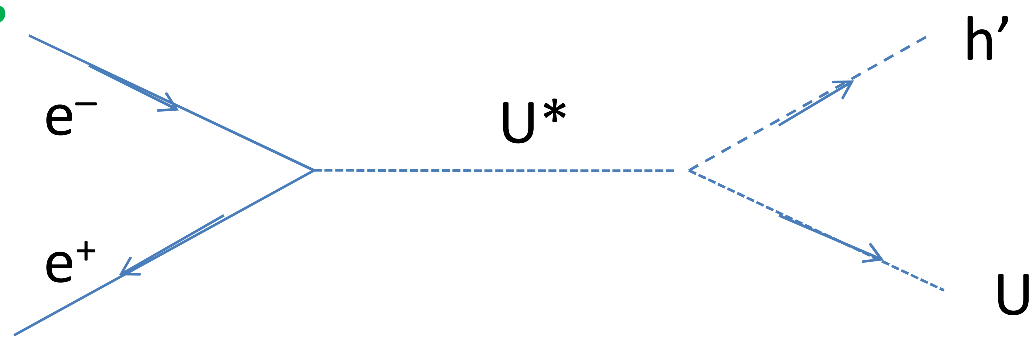


The cross section for this process is suppressed wrt the QED continuum by a factor k^2, so it can be at most ≈ 1 pb

The two leptons however resonate about the U mass, while the QED continuum events do not

S channel production

Probably the most interesting 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 DAFNE 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 (again assuming that the U decays only to SM particles) would then be a pair of leptons + missing energy

Experimental detection

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

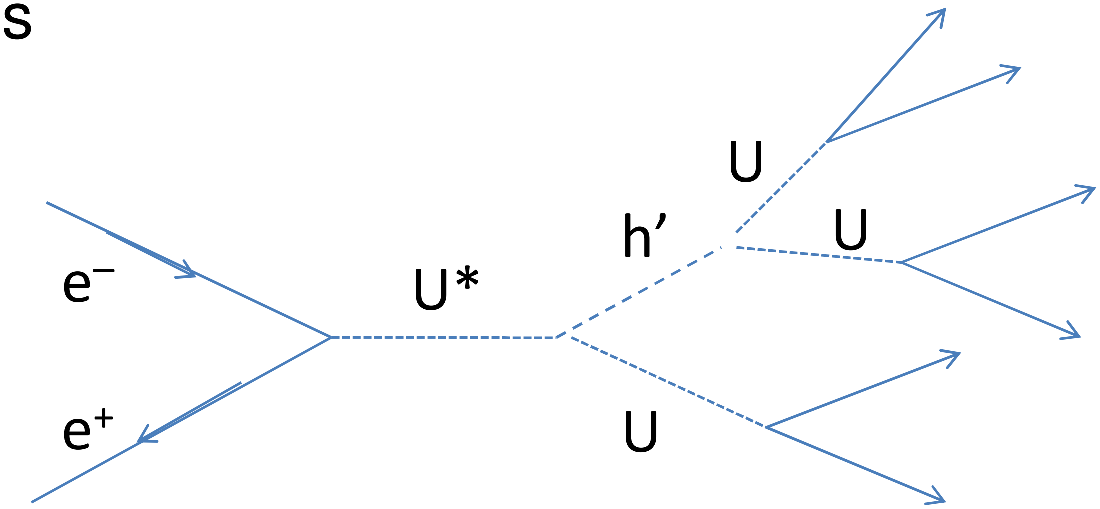
A possible background specific to DAFNE is $K_S \rightarrow \pi^+\pi^-$, with the parent K_L flying through the apparatus

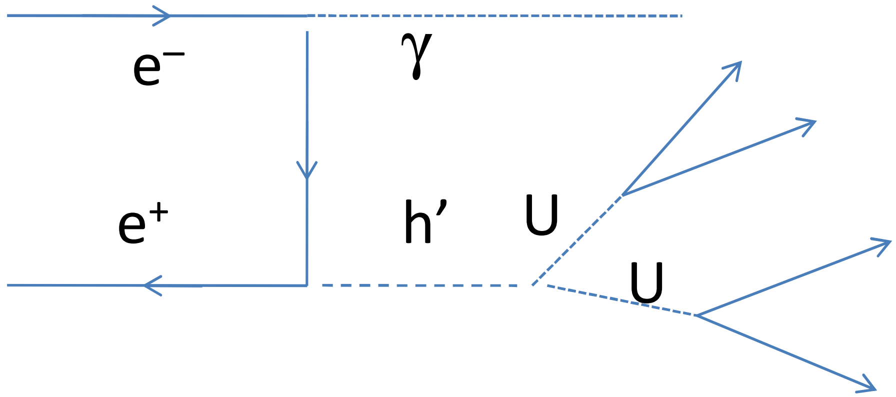
This should be a problem only for the muon channel and for masses of the U boson close to m_K. It can however be well calibrated by using K crash events

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

Spectacular final states

If $m_{h'} > 2\ m_U$ then the higgs' decays mainly into two U bosons giving rise to spectacular 4 leptons+g or 6 leptons final states





Conclusions

- $|V_{us}|f_+(0)$ @ 0. 14%   (5 fb^{-1} are enough to do the job).
- Unitarity test at few 10^{-4} , with lattice improvements on form factors.
- Improve constraints on New Physics and interplay with other sectors.
- at the moment all KLOE results are compatible with no CPT violation.
- Neutral kaon interferometry, CPT symmetry and QM tests are among the main issues of the KLOE-2 physics program. Measurements will benefit from both a huge data sample (20-50 fb^{-1}) and a better detector.
- moreover…. KLOE-2 can cover an interesting region of the dark matter parameter space in terms of the mixing parameter with the "standard sector" and mass.