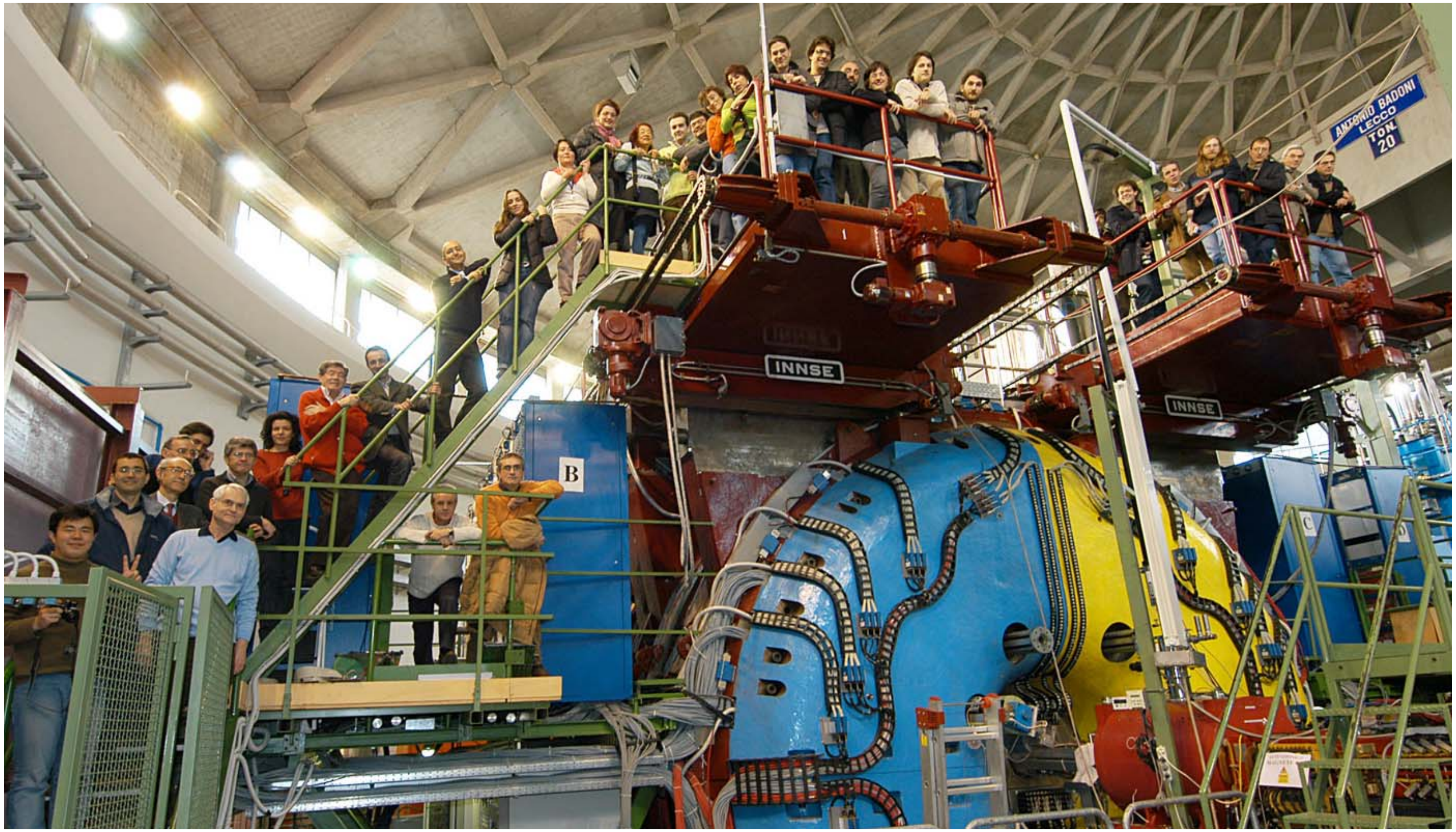
Il progetto KLOE-2

Antonio Di Domenico

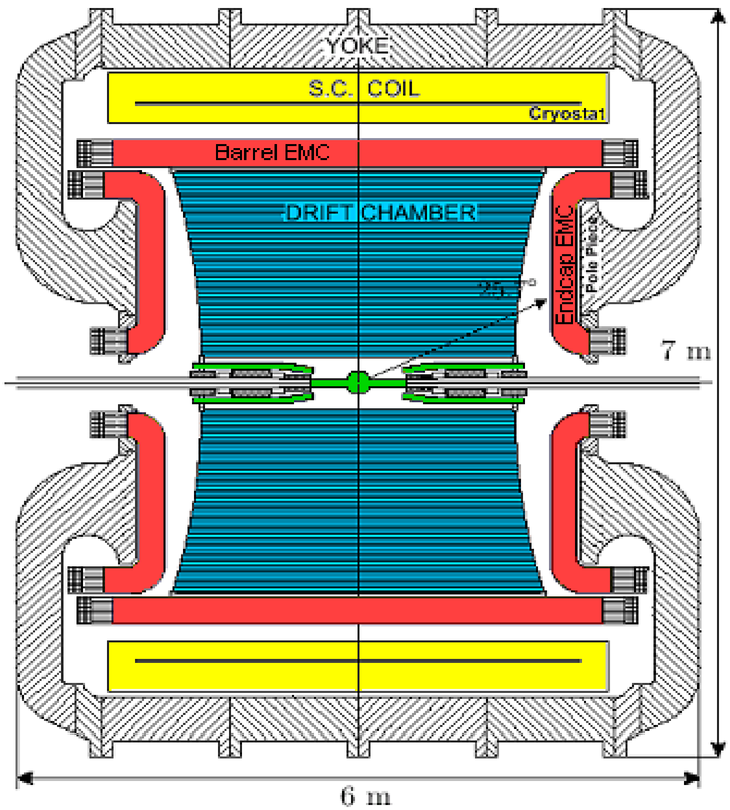


Congressino sulle prospettive della Sezione di Roma
4 maggio 2009

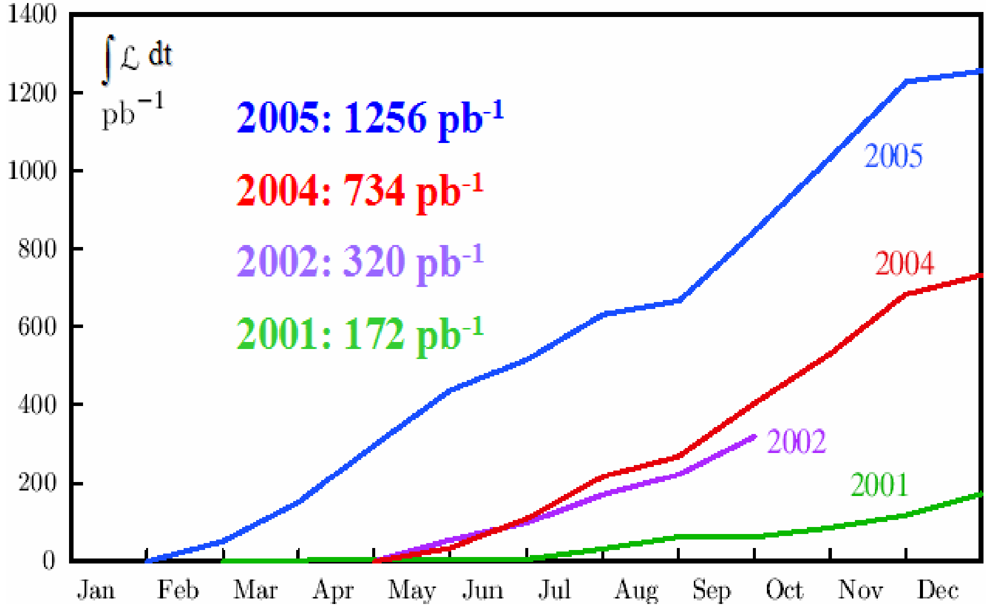
KLOE at DAΦNE

•$e^+e^- \to \phi$ σ_ϕ~3 μb
W = m_ϕ = 1019.4 MeV

$\phi \to$KK, ρπ, ηγ, ….
(highly pure K_S,K_L, K^+, K^- beams)



Integrated luminosity (KLOE)



Max ℒ ~ 1.4 $\times 10^{32}$ $cm^{-2}s^{-1}$

Day performance: 7-8 pb^{-1}
Total KLOE ∫ℒ dt ~ 2.5 fb^{-1}
(2001 - 05)

→ ~2.5×10^9 K_SK_L pairs
→ ~3.6×10^9 K^+K^- pairs

Collaborazione KLOE

La collaborazione KLOE è composta da 80 fisici

Ad oggi 43 lavori pubblicati (PLB, JHEP, EPJC)
di cui 11 con "corresponding author" del gruppo di Roma

89 risultati ottenuti da KLOE citati nelle sezioni "light unflavored mesons" e "strange mesons" del Particle Data Group 2008

Il gruppo di Roma:

Cesare Bini
Valerio Bocci
Antonio De Santis
Guido De Zorzi
Antonio Di Domenico
Salvatore Fiore
Paolo Franzini
Paolo Gauzzi
Enrico Pasqualucci

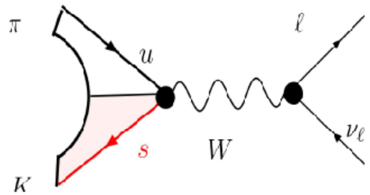
Principali risultati:

- misura dei principali parametri fisici e canali di decadimento del K_S , K_L e $K^{\pm}$
- misura di V_{us} , universalità leptonica e test della matrice CKM
- Interferometria con mesoni K neutri:
  test della simmetria CPT e della meccanica quantistica
- studio delle proprietà dei mesoni scalari leggeri $f_0(980)$, $a_0(980)$
- studio delle proprietà dei mesoni pseudoscalari leggeri η e η'
- misura della sezione d'urto adronica e anomalia del muone (g-2)

KLOE physics papers

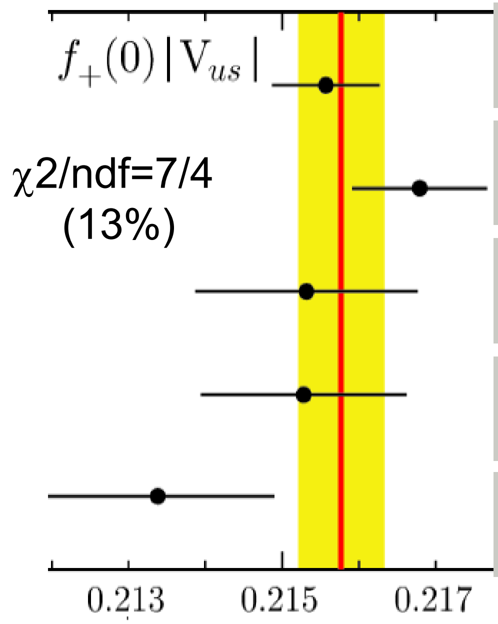
1) F. Ambrosino, et al., Study of the a_0(980) meson via the radiative decay phi->eta pi^0 gamma with the KLOE detector. arXiv:0904.2539. submitted to Phys.Lett.B
2) F. Ambrosino, et al., Search for the decay phi -> K0 K0bar gamma with the KLOE experiment. arXiv:0903.4115. submitted to Phys.Lett.B
3) F. Ambrosino, et al., Measurement of the branching ratio and search for a CP violating asymmetry in the eta ---> pi+ pi- e+ e- (gamma) decay at KLOE. arXiv:0812.4830. Phys.Lett.B675:283-288,2009.
4) F. Bossi, et al., Precision Kaon and Hadron Physics with KLOE. arXiv:0811.1929. Riv.Nuovo Cim. 031:531-623,2008.
5) F. Ambrosino, et al., Search for the K(S) ---> e+e- decay with the KLOE detector. arXiv:0811.1007. Phys.Lett.B672:203-208,2009.
6) F. Ambrosino, et al., Measurement of sigma(e + e- ---> pi+ pi- gamma(gamma) and the dipion contribution to the muon anomaly with the KLOE detector. arXiv:0809.3950. Phys.Lett.B670:285-291,2009.
7) F. Ambrosino, et al., Study of the process e+e- ---> omega pi0 in the phi-meson mass region with the KLOE detector. arXiv:0807.4909. Phys.Lett.B669:223-228,2008.
8) F. Ambrosino, et al., Measurement of the absolute branching ratio of the K+ ---> pi+ pi0 (gamma) decay with the KLOE detector. arXiv:0804.4577. Phys.Lett.B666:305-310,2008.
9) F. Ambrosino, et al., Search for the K(S) ---> e+ e- decay with the KLOE detector at DAFNE. arXiv:0707.2687. Phys.Lett.B672:203-208,2009.
10) F. Ambrosino, et al., Measurement of the pseudoscalar mixing angle and eta-prime gluonium content with KLOE detector. hep-ex/0612029. Phys.Lett.B648:267-273,2007.
11) F. Ambrosino, et al., First observation of quantum interference in the process phi ---> K(S) K(L) ---> pi+ pi- pi+ pi-: A Test of quantum mechanics and CPT symmetry. hep-ex/0607027. Phys.Lett.B642:315-321,2006.
12) F. Ambrosino, et al., Measurement of the branching ratio of the K(L) ---> pi+ pi- decay with the KLOE detector. hep-ex/0603041. Phys.Lett.B638:140-145,2006.
13) F. Ambrosino, et al., Measurement of the form- factor slopes for the decay K(L) ---> pi+- e- + nu with the KLOE detector. hep-ex/0601038. Phys.Lett.B636:166-172,2006.
14) F. Ambrosino, et al., Study of the branching ratio and charge asymmetry for the decay K(s) ---> pi e nu with the KLOE detector. hep-ex/0601026. Phys.Lett.B636:173-182,2006.
15) F. Ambrosino, et al., Study of the decay phi - --> f(0)(980) gamma ---> pi+ pi- gamma with the KLOE detector. hep-ex/0511031. Phys.Lett.B634:148-154,2006.
16) F. Ambrosino, et al., Measurement of the absolute branching ratio for the K+ ---> mu+ nu(gamma) decay with the KLOE detector. hep-ex/0509045. Phys.Lett.B632:76-80,2006.
17) F. Ambrosino, et al., Measurements of the absolute branching ratios for the dominant K(L) decays, the K(L) lifetime, and V(us) with the KLOE detector. hep-ex/0508027. Phys.Lett.B632:43-50,2006.
18) F. Ambrosino, et al., Measurement of the K(L) meson lifetime with the KLOE detector. hep-ex/0507088. Phys.Lett.B626:15-23,2005.
19) F. Ambrosino, et al., A Direct search for the CP-violating decay K(S) ---> 3p0 with the KLOE detector at DAFNE. hep-ex/0505012. Phys.Lett.B619:61-70,2005.
20) F. Ambrosino, et al., Measurement of the leptonic decay widths of the phi-meson with the KLOE detector. hep-ex/0411082. Phys.Lett.B608:199-205,2005.
21) F. Ambrosino, et al., Upper limit on the eta - --> pi+ pi- branching ratio with the KLOE detector. hep-ex/0411030. Phys.Lett.B606:276-280,2005.
22) A. Aloisio, et al., Measurement of sigma(e+e- --> pi+ pi- gamma) and extraction of sigma(e+e- --> pi+ pi-) below 1-GeV with the KLOE detector. hep-ex/0407048. Phys.Lett.B606:12-24,2005.
23) A. Aloisio, et al., Upper limit on the eta --- > gamma gamma gamma branching ratio with the KLOE detector. hep-ex/0402011. Phys.Lett.B591:49-54,2004.
24) A. Aloisio, et al., Measurement of the branching ratio for the decay K+- ---> pi+- pi0 pi0 with the KLOE detector. hep-ex/0307054. Phys.Lett.B597:139-144,2004.
25) M. Adinolfi, et al., Measurement of the ratio Gamma (K(L) ---> gamma gamma) / Gamma (K(L) - --> pi0 pi0 pi0) with the KLOE detector. hep-ex/0305035. Phys.Lett.B566:61-69,2003.
26) A. Aloisio, et al., Study of the decay phi --- > pi+ pi- pi0 with the KLOE detector. hep-ex/0303016. Phys.Lett.B561:55-60,2003,Erratum-ibid.B609: 449-450,2005.
27) A. Aloisio, et al., Measurement of Gamma (phi ---> eta-prime gamma) / Gamma (phi ---> eta gamma) and the pseudoscalar mixing angle. hep-ex/0206010. Phys.Lett.B541:45-51,2002.
28) A. Aloisio, et al., Measurement of Gamma(K(S) ---> pi+ pi- (gamma)) / Gamma(K(S) ---> pi0 pi0). hep-ex/0204024. Phys.Lett.B538:21-26,2002.
29) A. Aloisio, et al., Study of the decay phi --- > pi0 pi0 gamma with the KLOE detector. hep-ex/0204013. Phys.Lett.B537:21-27,2002.
30) A. Aloisio, et al., Study of the decay phi --- > eta pi0 gamma with the KLOE detector. hep-ex/0204012. Phys.Lett.B536:209-216,2002.
31) A. Aloisio, et al., Measurement of the branching fraction for the decay K(S) ---> pi e nu. hep-ph/0203232. Phys.Lett.B535:37-42,2002.
32) F. Ambrosino, et al., A Study of the Radiative K(L) ---> pi+- e-+ nu gamma Decay and Search for Direct Photon Emission with the KLOE Detector. arXiv:0710.3993. Eur.Phys.J.C55:539-546,2008.
33) F. Ambrosino, et al., Dalitz plot analysis of e+ e- ---> pi0 pi0 gamma events at s**(1/2) approximately M(phi) with the KLOE detector. hep-ex/0609009. Eur.Phys.J.C49:473-488,2007.
34) F. Ambrosino, et al., Measurement of the DAFNE luminosity with the KLOE detector using large angle Bhabha scattering. hep-ex/0604048. Eur.Phys.J.C47:589-596,2006.
35) F. Ambrosino, et al., Precise measurement of Gamma(K(s) ---> pi+ pi- (gamma))/Gamma(K(s) - --> pi0 pi0) with the KLOE detector at DAFNE. hep-ex/0601025. Eur.Phys.J.C48:767-780,2006.
36) F. Ambrosino, et al., |V(us)| and lepton universality from kaon decays with the KLOE detector. arXiv:0802.3009. JHEP 0804:059,2008.
37) F. Ambrosino, et al., Determination of eta ---> pi+ pi- pi0 Dalitz plot slopes and asymmetries with the KLOE detector. arXiv:0801.2642. JHEP 0805:006,2008.
38) F. Ambrosino, et al., Measurement of the absolute branching ratios for semileptonic K+- decays with the KLOE detector. arXiv:0712.3841. JHEP 0802:098,2008.
39) F. Ambrosino, et al., Measurement of the K(S) - --> gamma gamma branching ratio using a pure K(S) beam with the KLOE detector. arXiv:0712.1744. JHEP 0805:051,2008.
40) F. Ambrosino, et al., Measurement of the charged kaon lifetime with the KLOE detector. arXiv:0712.1112. JHEP 0801:073,2008.
41) F. Ambrosino, et al., Precise measurements of the eta and the neutral kaon meson masses with the KLOE detector. arXiv:0710.5892. JHEP 0712:073,2007.
42) F. Ambrosino, et al., Measurement of the K(L) - --> pi mu nu form-factor parameters with the KLOE detector. arXiv:0710.4470. JHEP 0712:105,2007.
43) F. Ambrosino, et al., Determination of CP and CPT violation parameters in the neutral kaon system using the Bell-Steinberger relation and data from the KLOE experiment. hep-ex/0610034. JHEP 0612:011,2006.

Vus, lepton universality and CKM unitarity at KLOE



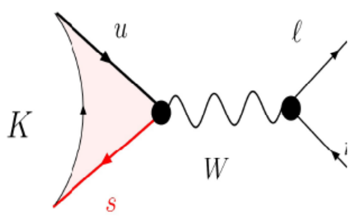
$\Gamma(K \to \pi l \nu(\gamma)) \propto |V_{us}|^2 \; |f_+^{K\pi}(0)|^2 \; I^l_K(\lambda_+,\lambda_0,0) \; (1 + \delta^l_K)$

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



χ2/ndf=7/4 (13%)

		err %
$K_L e3$	0.2155(7)	0.3
$K_L \mu 3$	0.2167(9)	0.4
$K_S e3$	0.2152(14)	0.7
$K^\pm e3$	0.2152(13)	0.6
$K^\pm \mu 3$	0.2132(15)	0.7



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

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

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

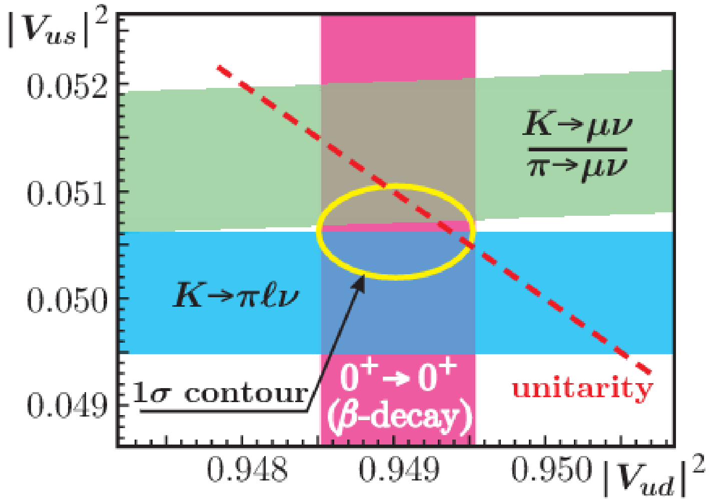
All KLOE exp. inputs but K_S lifetime

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

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

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

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



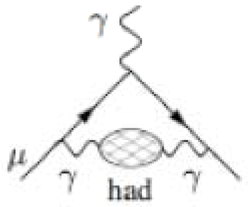
$1-|V_{ud}|^2-|V_{us}|^2 = 4(7)\mathrm{x}10^{-4}$ @0.6σ

World Average: 6x10^{-4} accuracy

$\sigma(e^+e^- \to \pi^+\pi^-\gamma(\gamma))$ measurement

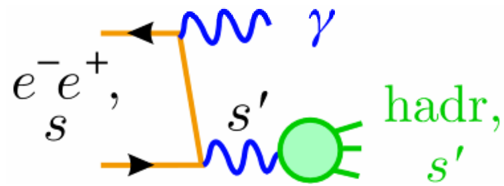
The comparison between experiment and theory for the muon anomaly a_μ is a precise test of SM

Theoretically, the error on a_μ is dominated by the hadronic contribution, that have to be evaluated from data



$e^+e^- \to \pi^+\pi^-$ in the range < 1 GeV contributes 70% to δa_μ^{Had}!

measurement of $\sigma(e^+e^- \to \pi^+\pi^-\gamma)$ at fixed $\sqrt{s}$ using ISR to extract $\sigma(e^+e^- \to \pi^+\pi^-)$ for $\sqrt{s'}$ from $2M_\pi$ to $\sqrt{s}$

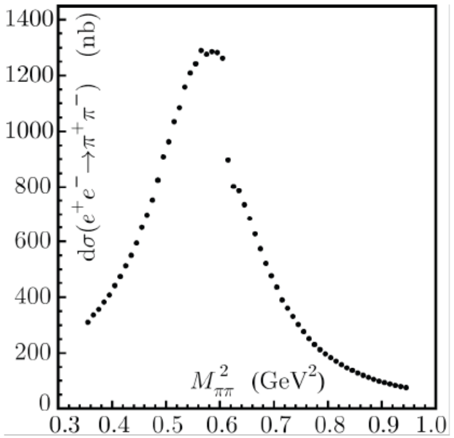


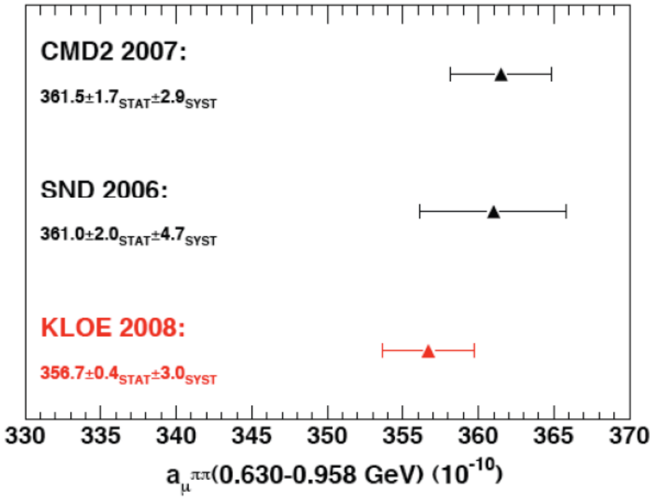
Neglecting FSR effects:

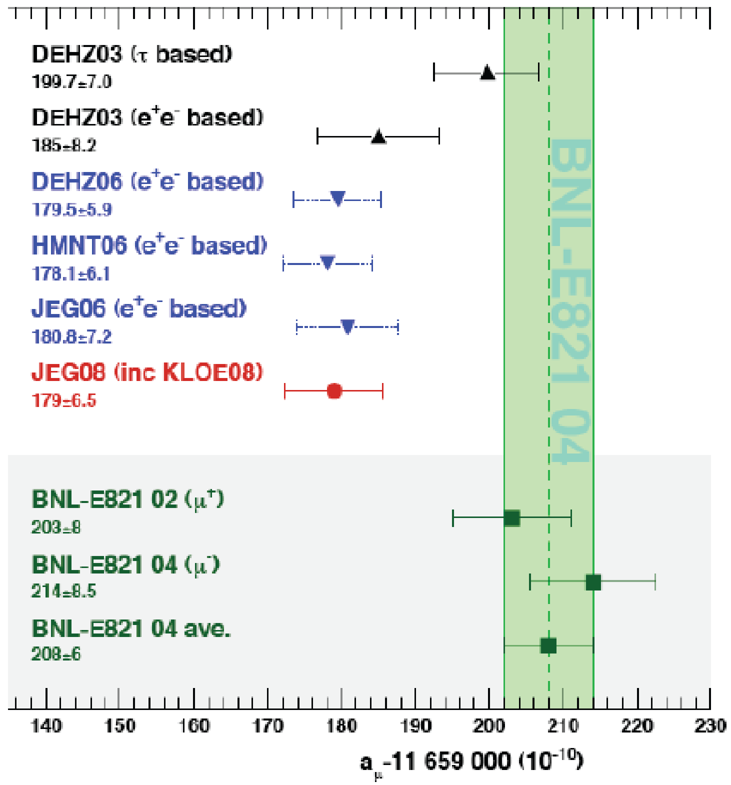
$$s\frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \sigma_{\pi\pi}(s) \times H(s)$$

precise calculations of the radiator function H(*s*) [MC NLO generator EPJC27(2003)]

$$a_m^{pp}(0.35\text{-}0.95\,\text{GeV}^2) = (387.2 \pm 0.5_{stat} \pm 2.4_{sys} \pm 2.3_{theo}) \cdot 10^{-10}$$

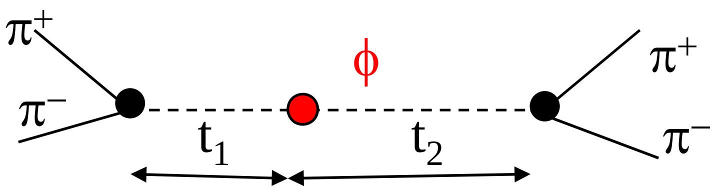




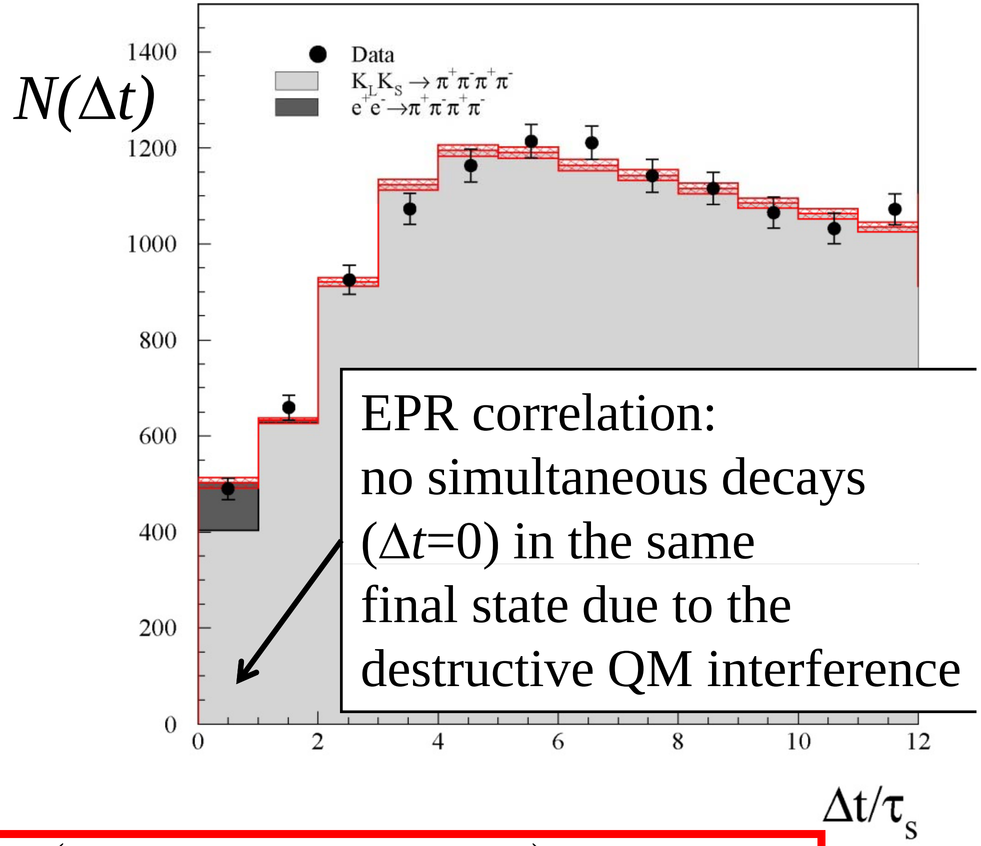


Neutral kaon interferometry

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



$\Delta t = |t_1 - t_2|$



Most precise test of quantum coherence in an entangled system:

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

ζ decoherence parameter (QM predicts $\zeta=0$)

Quantum gravity effects might induce:

1) decoherence and CPT violation (at most γ=O(m_K^2/M_{Planck})~2x10^{-20} GeV) →

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

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

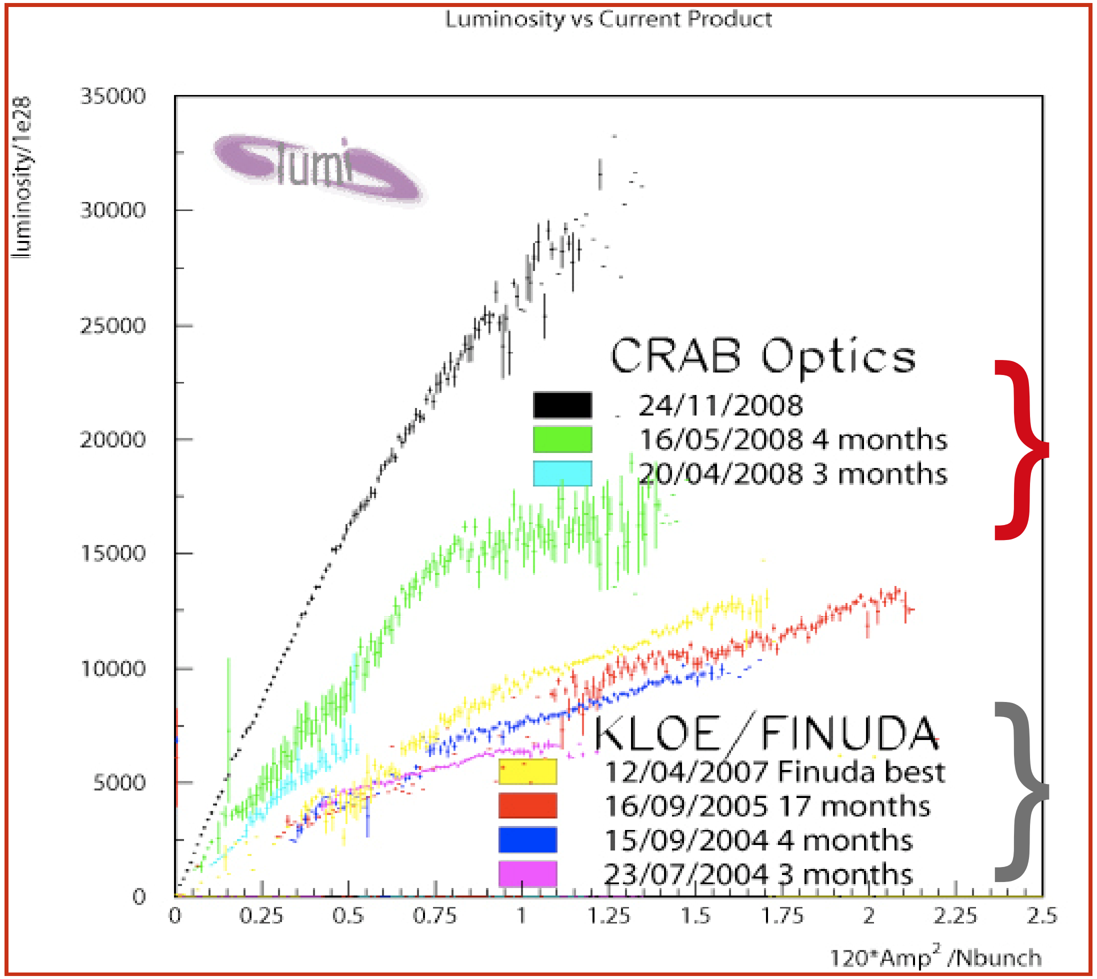
$$|i\rangle \propto \left(K^0\overline{K}^0 - K^0\overline{K}^0\right) + \omega\left(K^0\overline{K}^0 + K^0\overline{K}^0\right)$$

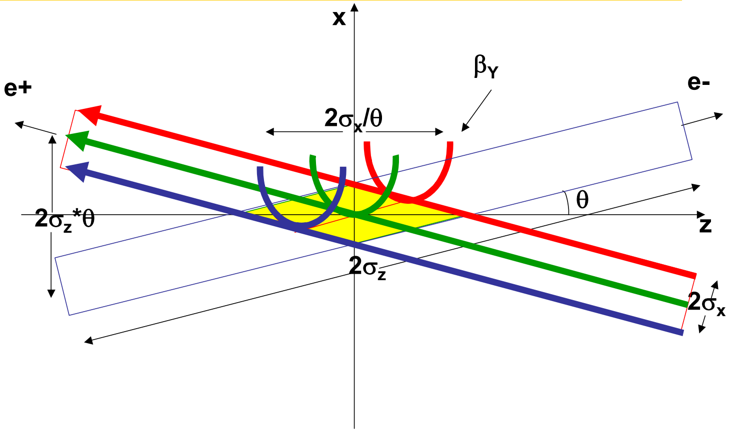
$$\Re\omega = \left(-1.6^{+3.0}_{-2.1\,STAT} \pm 0.4_{SYST}\right)\times 10^{-4}$$

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

DAΦNE Luminosity versus colliding currents

Crabbed waist scheme at DAΦNE (by P. Raimondi)





Crabbed waist is realized with a sextupole in phase with the IP in X and at $\pi/2$ in Y

Large Piwinski angle
Crab-Waist compensation SXTs

original collision scheme

expected at KLOE-2 : L_{int} ~ 20 pb^{-1}/day x 200 dd/year = 4 fb^{-1} /year

KLOE-2 at upgraded DAΦNE

Feasibility studies: Begin at the end of 2005 for INFN 2006 roadmap

Working group on e^+e^- physics at Frascati: C. Bini, P. Gauzzi et al...

→ "Prospects for e+e- physics at Frascati ....", EPJC 50 (2007) 729-768

Working group on kaon physics: A. Di Domenico et al..

→ "Handbook on neutral kaon interferometry at a ϕ-factory" Frascati Phys. Series Vol. 43 (2007)

Recent update of the physics program: KLOE-2 physics workshop 9-10 aprile 2009

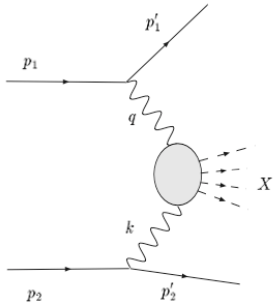
- -K_S physics: A_S, τ_S, rare and semi-rare decays $K_S \to \pi e \nu$, $K_S \to \pi \mu \nu$, $K_S \to \gamma\gamma$, $K_S \to 3\pi$, …
- -V_{us} and CKM unitarity
- -Neutral kaon interferometry, tests of CPT, QM and Lorentz symmetry with neutral kaons
- -Search for exotic particles
- -Light pseudoscalar η ed η' decays, e.g. $\eta' \to \eta\pi\pi$
- -Light scalars $\phi \to KK\gamma$
- - $\gamma\gamma$ physics, $\gamma\gamma \to \pi^0\pi^0$ search for the σ meson,
- - hadronic cross section and g-2 : run at 1 GeV and/or energy scan

KLOE-2 plan:

- step 0 (approved): begin dec.2009; goal: $L \sim 5$ fb^{-1}
  detector upgrade: $\gamma\gamma$ tagger
- step1: begin 2011(?) ; goal: $L > 20$ fb^{-1}
  detector upgrade: inner tracker, photon veto detectors (forward + inner quadrupoles)
- step2: begin (?) : energy scan, L ~few fb^{-1} (for σ_{had} and (g-2))
  requires Dafne upgrade; 2 options: (1) E_{max} =1.4 GeV (2) E_{max} = 2.5 GeV

$\gamma\gamma$ physics

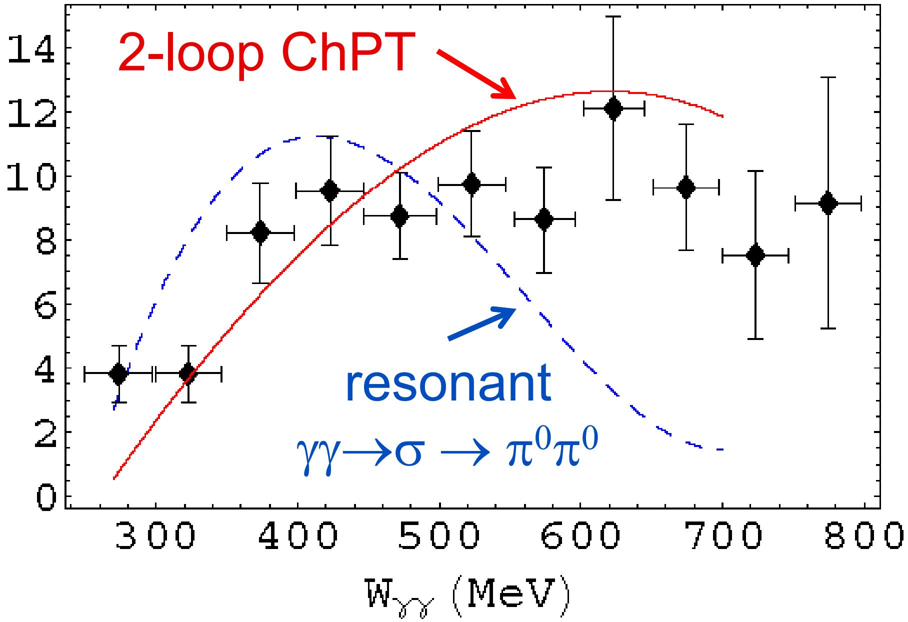
$$e^+e^- \to \gamma^*\gamma^* \to e^+e^- + X \qquad X = \pi^0\pi^0,\ \pi^0,\ \eta,\ \ldots$$

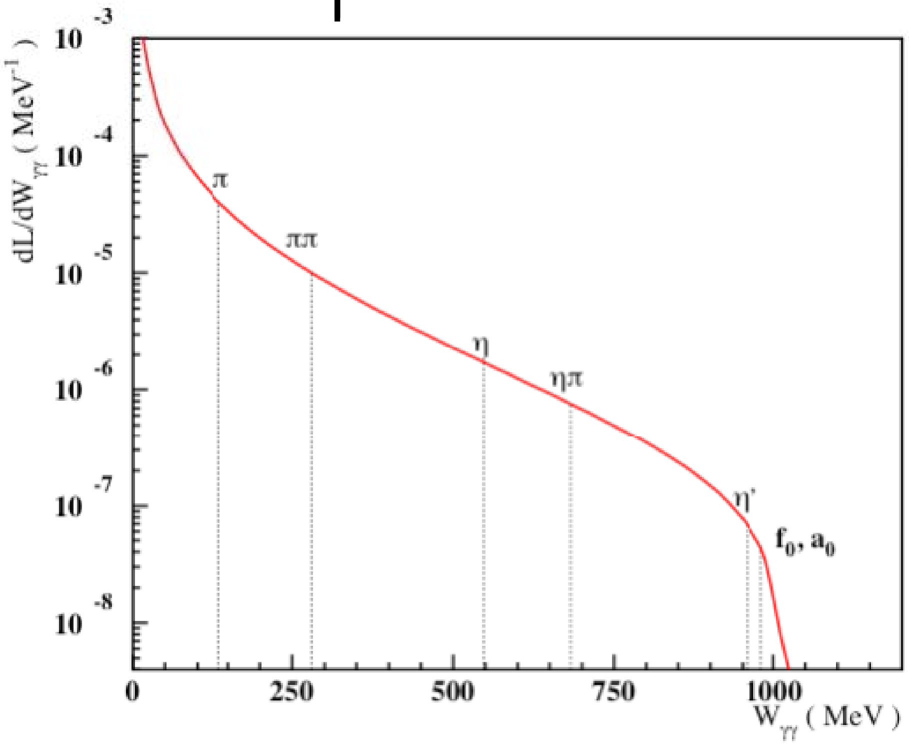


- $\sigma \propto \alpha^4 \ln^2(s)$ (vs α^2/s with 1 γ)
- Photon propagator $1/q^2$
  --> quasi real photon -->
  Small angle electrons $\theta = 1/\gamma$
- $J^{PC}(X) = 0^{\pm+}, 2^{\pm+}$ (vs $J^{PC} = 1^{--}$ with 1 γ)

$$\frac{dN_X}{dW_{\gamma\gamma}} = L_{int} \frac{dL}{dW_{\gamma\gamma}} \sigma(\gamma\gamma \to X)$$

$\gamma\gamma \to \pi^0\pi^0$





γγ physics with tagging at KLOE

$$e^+e^- \rightarrow \gamma^*\gamma^* \rightarrow e^+e^- + \pi^0\pi^0$$

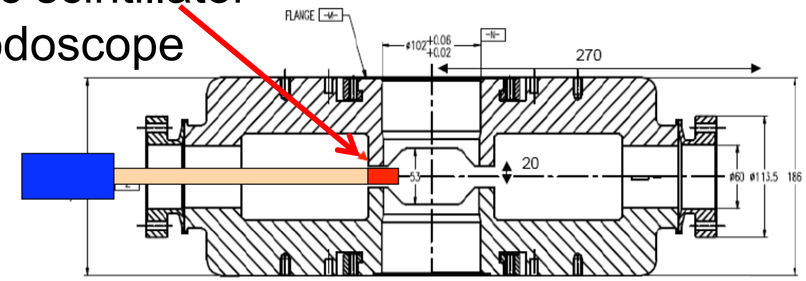
e^+e^- → to tagger

$\pi^0\pi^0$ → inside KLOE

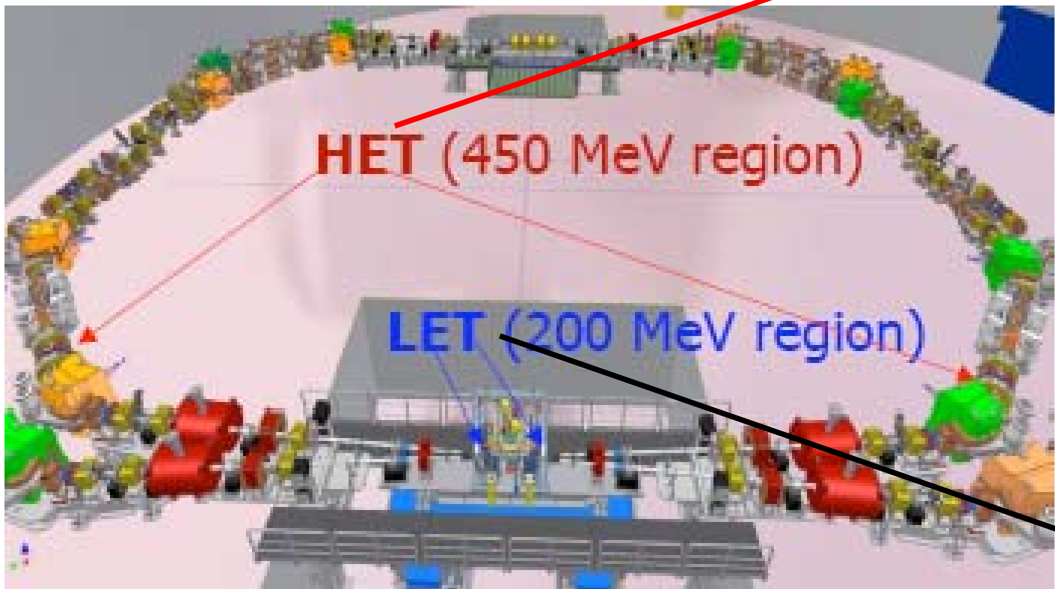
with 5 fb^{-1}
prev. data points
at ~2-3% error

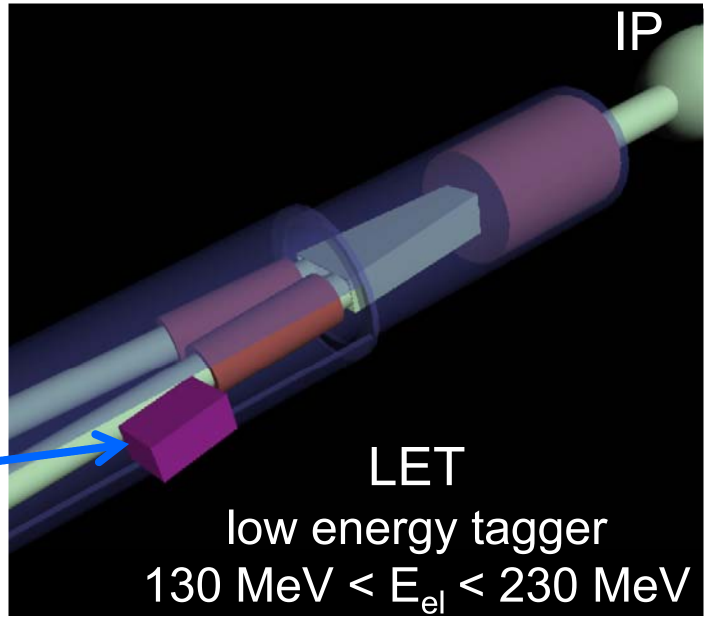
HET high energy tagger
430 MeV < E_{el} < 470 MeV

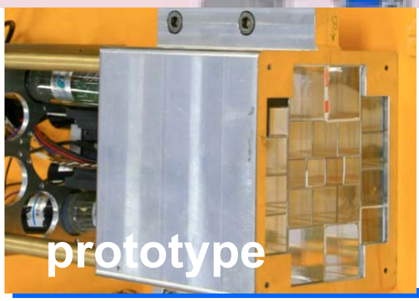
plastic scintillator hodoscope



vacuum pipe



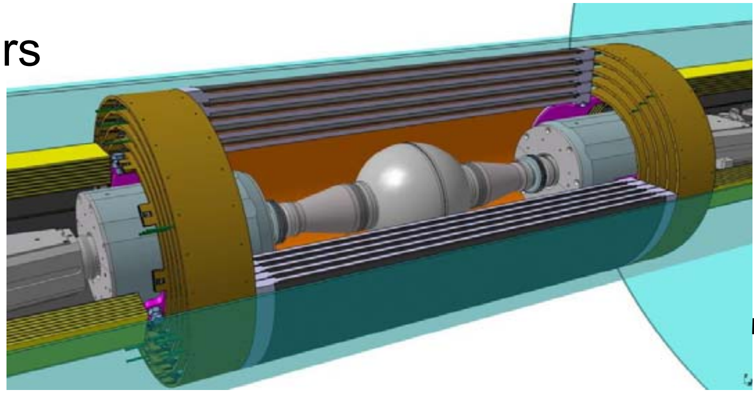


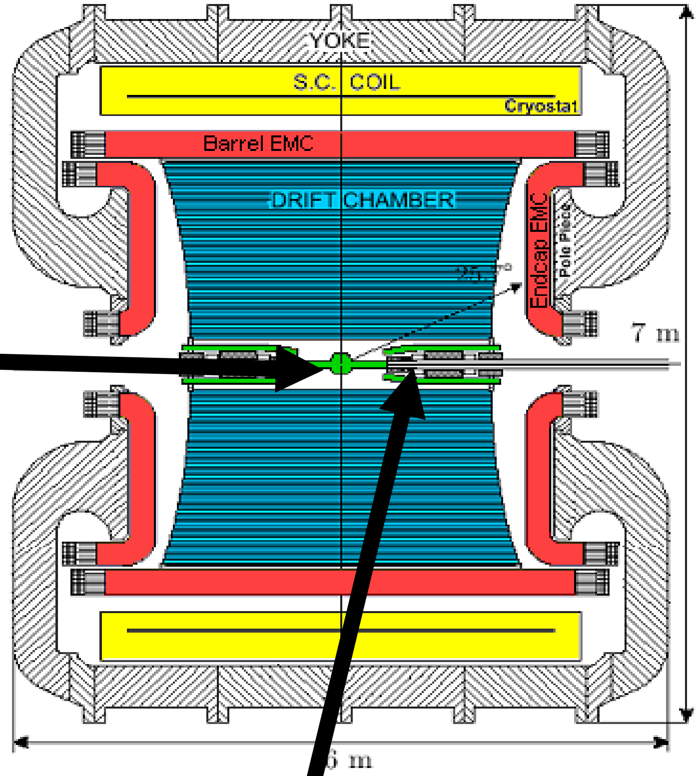


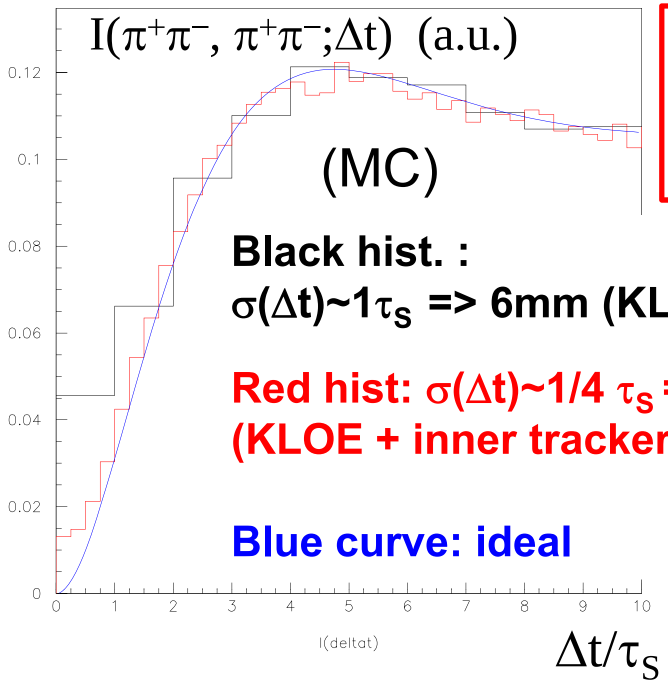
EM calorimeters
2 x 2 x 13 cm^3
LYSO crystal matrix
SiPM read-out

Step-1: detector upgrade

Inner tracker:
5 cylindrical GEM layers
Spatial resolution
200 μm $\sigma_{r\varphi}$
500 μm σ_Z
L=70cm R=13,25 cm
1.8% X_0







Black hist. :
$\sigma(\Delta t) \sim 1\tau_S$ => 6mm (KLOE)

Red hist: $\sigma(\Delta t) \sim 1/4\ \tau_S$ => 1.5mm (KLOE + inner tracker)

Blue curve: ideal

L>20 fb^{-1} + inner tracker improve precision on ζ, γ, ω etc. by a factor ~ 10

Other upgrades:

- QCAL-T calorimeter surrounding inner quadrupole region for K_L photon veto
- CCAL-T forward photon veto calorimeter for background rejection

Conclusioni

1) L’esperimento KLOE ha ottenuto numerosi risultati nel settore della fisica dei K e della fisica adronica di bassa energia.

2) Prestazioni di DAFNE migliorate con lo schema “crabbed waist”.

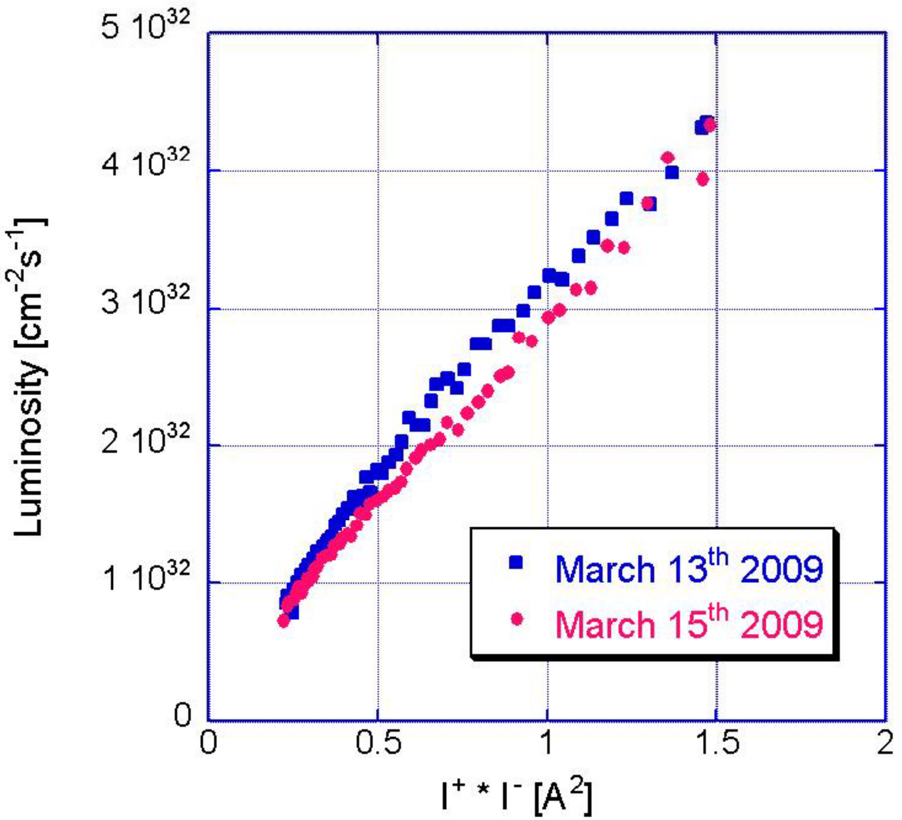
3) La collaborazione KLOE-2 si propone di approfondire e completare il programma di fisica a DAFNE su fisica dei K e fisica adronica.

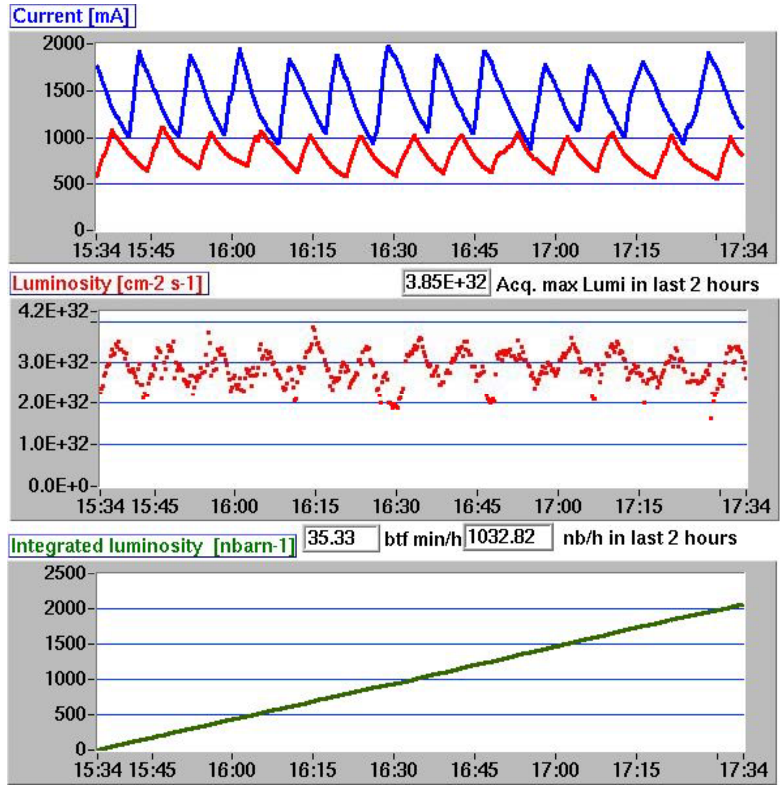
4) La presa dati (step-0) inizierà a fine 2009 ; prevista installazione di tagger per fisica $\gamma\gamma$

5) Tesi disponibili su vari argomenti (interferometria quantistica, fisica $\gamma\gamma$, etc.)

DAΦNE Luminosity versus colliding currents

15 March 2009, record on peak luminosity: **4.36x10^32 cm^{-2} s^{-1}**, I-=1470, I+=1003, 105 bunches



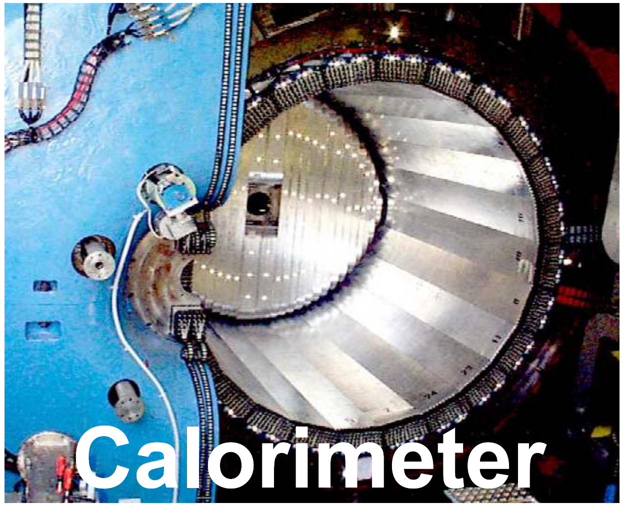


December 21 2008: L = 4.0x10^32 cm^{-2} s^{-1} integrated luminosity of **1pb^{-1}/h** (in quasi-topping-up mode).

expected improvements (~+20%)
- reducing e+ beam instabilities
- increasing beam lifetime

expected at KLOE-2 : L_{int} ~ 20-25 pb^{-1}/day x 200 dd/year = 4-5 fb^{-1} /year

The KLOE detector at DAΦNE



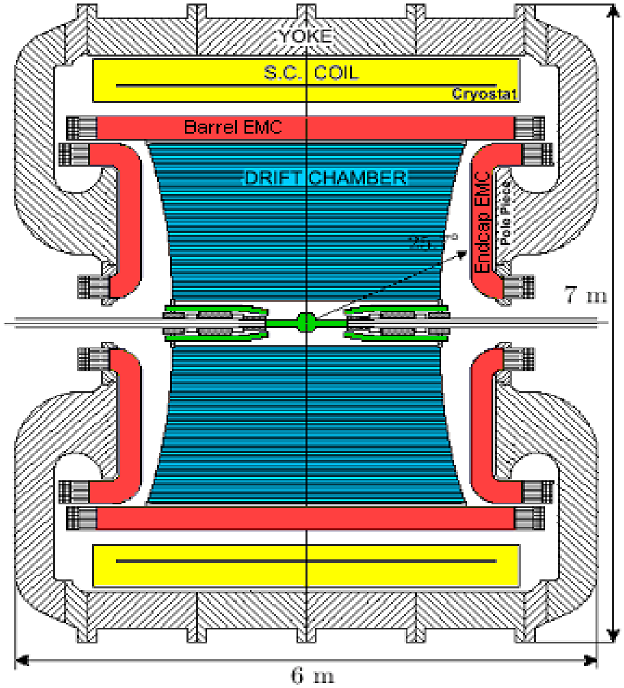
Lead/scintillating fiber

4880 PMTs

98% coverage of solid angle

Superconducting coil

B = 0.52 T



4 m diameter × 3.3 m length

90% helium, 10% isobutane

12582/52140 sense/total wires

All-stereo geometry

$\sigma_E/E \cong 5.7\% /\sqrt{E(\mathrm{GeV})}$

$\sigma_t \cong 54$ ps $/\sqrt{E(\mathrm{GeV})} \oplus 50$ ps

(relative time between clusters)

$\sigma_{\gamma\gamma} \sim 2$ cm (π^0 from $K_L \to \pi^+\pi^-\pi^0$)

$\sigma_p/p \cong 0.4$ % (tracks with $\theta > 45°$)

$\sigma_x^{hit} \cong 150$ μm (xy), 2 mm (z)

$\sigma_x^{vertex} \sim 1$ mm