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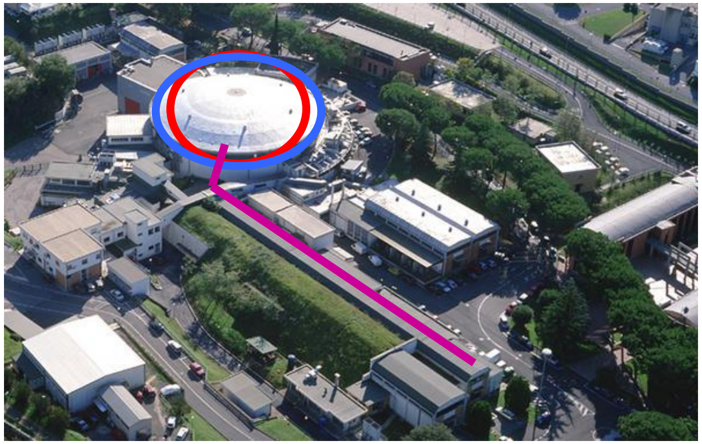
Determination of V_{us} at the KLOE experiment: present results and future perspectives

KLOE at DAΦNE ϕ-factory

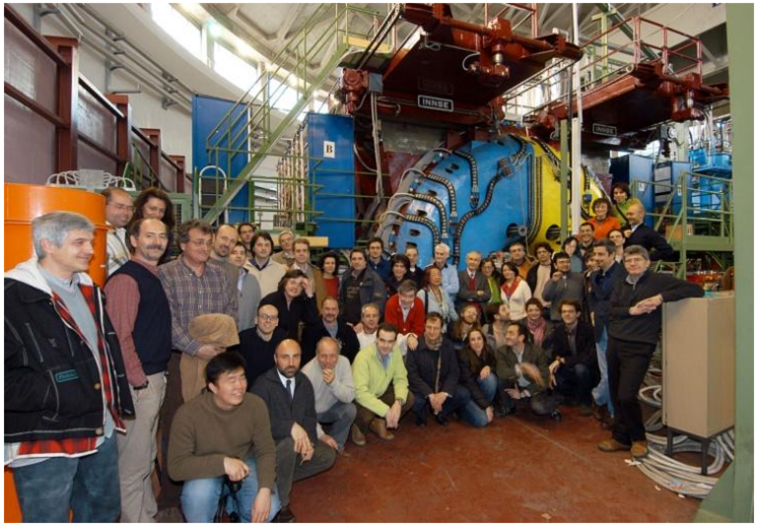
Frascati ϕ-factory DAϕNE:
an e^+e^- collider @ $\sqrt{s}$ =1019.4 MeV = M_ϕ

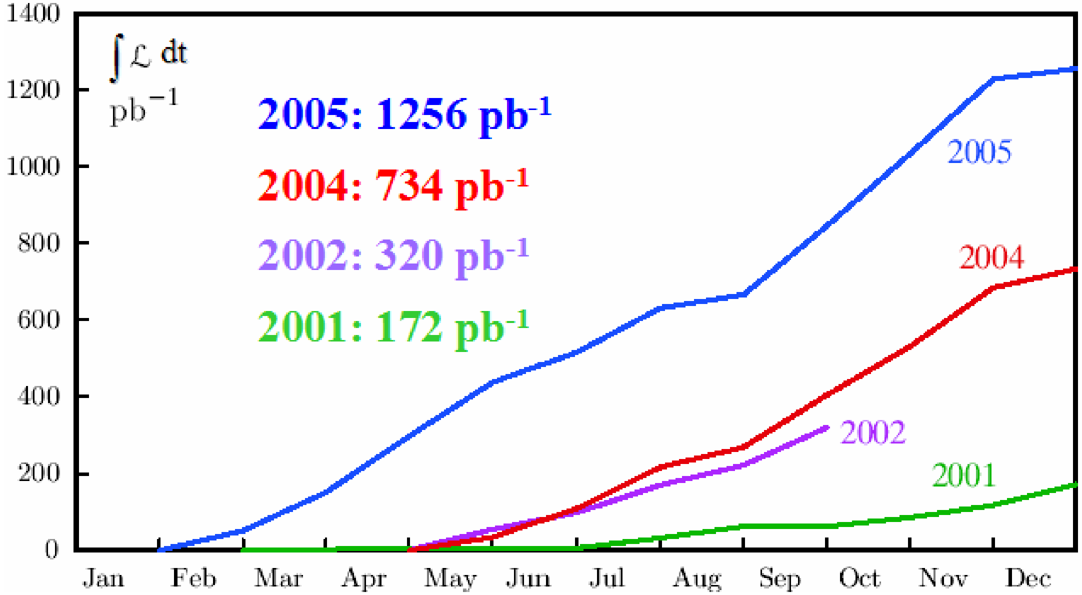
Best performance in 2005:

- ✓ $L_{peak} = 1.4 \times 10^{32}$ cm^{-2}s^{-1}
- ✓ $\int L dt$ = 8.5 pb^{-1}/day



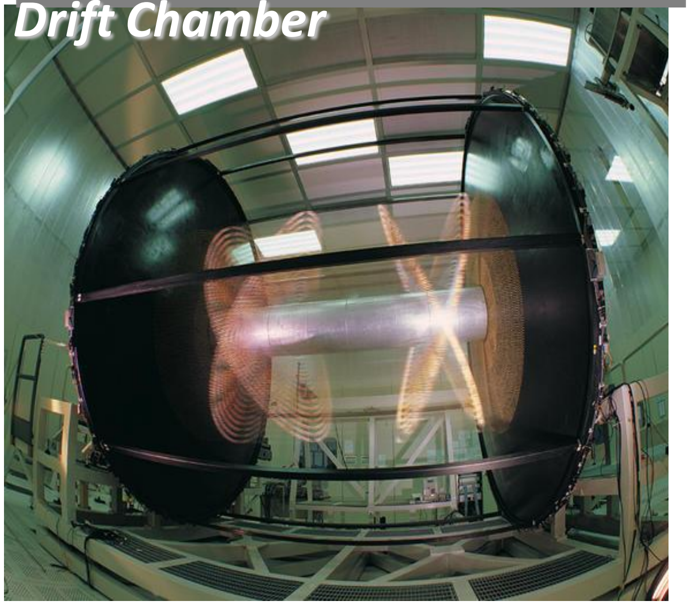
KLOE has acquired 2.5 fb^{-1} @ $\sqrt{s}=M_\phi$ (2001-05)
+ 250 pb^{-1} *off-peak* @ $\sqrt{s}$=1 GeV





KLOE at DAΦNE ϕ-factory

- 4 m diameter 3.3 m length
- 90% helium, 10% isobutane
- 12582/52140 sense/tot wires
- All-stereo geometry



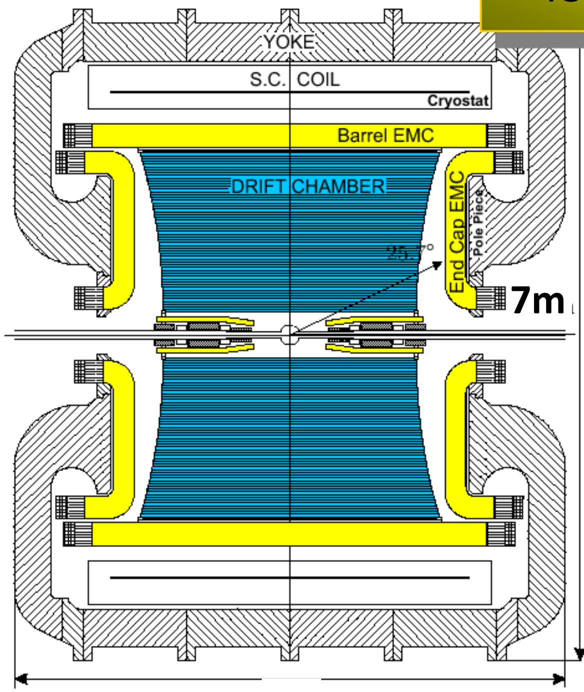
$\sigma_{r\phi}$ = 150 μm σ_z = 2 mm

σ_V = 3 mm σ_p/p = 0.4 %

λ_{KS} = 0.6 cm

λ_{KL} = 340 cm

$\lambda_{K\pm}$ = 95 cm



B = 0.52 T

- Lead/scintillating fiber
- 98% coverage of solid angle
- 88 modules (barrel + end-caps)
- 4880 PMTs (two side read-out)

$\sigma_E/E = 5.4\%/\sqrt{E(GeV)}$

$\sigma_t = 54\ ps/\sqrt{E(GeV)} \oplus 50\ ps$(calib)

V_{us} and V_{us}/V_{ud} from Kaon decays

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

$\Gamma(K_{l3(\gamma)})$

- Precise determination of V_{us}
- Test of Lepton universality Ke3 vs Kμ3
- Most precise test of CKM unitarity

  $|V_{ud}|^2 + |V_{us}|^2 = 1$ $|V_{ub}|^2$ **negligible**
- Lepton-Quark universality of weak int.

  $G_F^2 \equiv G_{CKM}^2 = (|V_{ud}|^2 + |V_{us}|^2) G_F^2$

$\Gamma(K_{\mu2(\gamma)})/\Gamma(\pi_{\mu2(\gamma)})$

- Precise determination of V_{us}/V_{ud}
- Test of Physics beyond the SM
  - right-handed contributions to charged weak currents
  - charged Higgs exchange (2 Higgs doublet scenarios)

$$\frac{\Gamma(K_{\mu2(\gamma)})}{\Gamma(\pi_{\mu2(\gamma)})} = \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K}{f_\pi} \times \frac{M_K(1-m_\mu^2/M_K^2)^2}{m_\pi(1-m_\mu^2/m_\pi^2)^2} \times (1+\alpha(C_K - C_\pi))$$

KLOE has measured all relevant inputs for charged & neutral kaons:

BR's, lifetimes (K_L, K , K_S), form factors (FFs)

To extract V_{us} from K_L, K_S and $K^{\pm}$

PLB 632 (2006)

$BR(K_{Le3}) = 0.4008(15)$ 0.37%

$BR(K_{L\mu3}) = 0.2699(14)$ 0.52%

PLB 626 (2005)

$\tau_L = 50.92(30)$ ns 0.58%

PLB 636 (2006)

$BR(K_S \to \pi e \nu) = 7.046(91) \times 10^{-4}$

1.3%

PLB 636 (2006)

$\lambda'_+ \times 10^3$	$\lambda''_+ \times 10^3$
25.5 ± 1.8	1.4 ± 0.8

JHEP12(2007)

$\lambda_+' = (25.6 \pm 1.5_{stat} \pm 0.9_{syst})\times 10^{-3}$

$\lambda_+'' = (1.5 \pm 0.7_{stat} \pm 0.4_{syst})\times 10^{-3}$

$\lambda_0 = (15.4 \pm 1.8_{stat} \pm 1.3_{syst})\times 10^{-3}$

PLB 632 (2006)

$BR(K^+ \to \mu^+ \nu) = 0.6366(17)$

0.27%

JHEP 01 (2008)

$\tau^{\pm} = 12.347(30)$ 0.24%

JHEP 02 (2008)

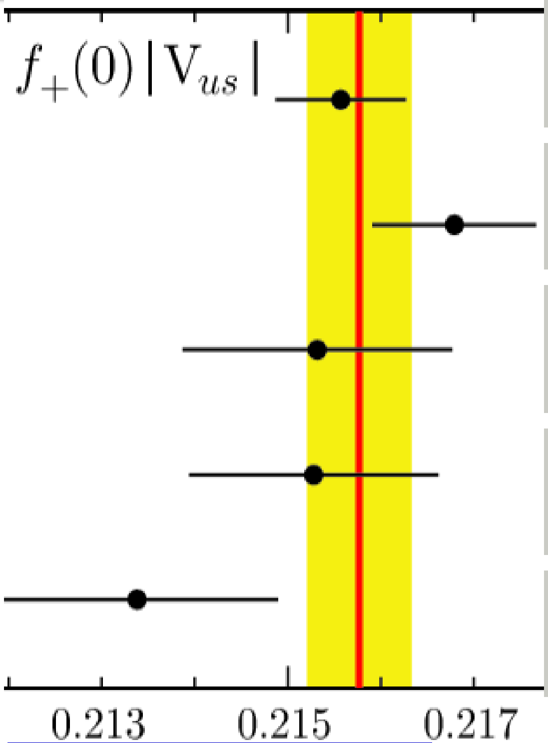
$BR(K^{\pm} \to \pi^0 e^{\pm} \nu) = 0.04965(53)$ 1%

$BR(K^{\pm} \to \pi^0 \mu^{\pm} \nu) = 0.03233(39)$ 1.2%

PLB 666 (2008)

$BR(K^+ \to \pi^+ \pi^0 (\gamma)) = 0.2065(9)$ 0.43%

$|V_{us}| f_+(0)$ at KLOE



		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

All KLOE exp. inputs but K_S lifetime

2010: KLOE result on K_S lifetime

Lepton universality

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

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

τ decays: $(r_{\mu e})_\tau = 1.0005(41)$ (PDG06)

π decays: $(r_{\mu e})_\pi = 1.0042(33)$

JHEP04(2008)059

KLOE average $|V_{us}| f_+(0) = 0.2157(6)$ $\chi 2/ndf = 7/4$ (13%)

World Average 0.2163(5)

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

$1 - |V_{ud}|^2 - |V_{us}|^2 = 9(8) \times 10^{-4}$

$f_+(0) = 0.964(5)$ — **PRL 100 (2008)**

$|V_{ud}| = 0.97418(26)$ — **PRC 77 (2008)**

V_{us}, V_{ud} and V_{us}/V_{ud}

$|V_{us}/V_{ud}| = 0.2323(15)$ — $BR(K^\pm \to \mu^\pm \nu) = 0.6366(17)$, $f_K/f_\pi = 1.189(7)$

PLB 632 (2006)

PRL 100 (2008)

$|V_{us}| = 0.2237(13)$ from Kl3 decays

$|V_{ud}| = 0.97418(26)$

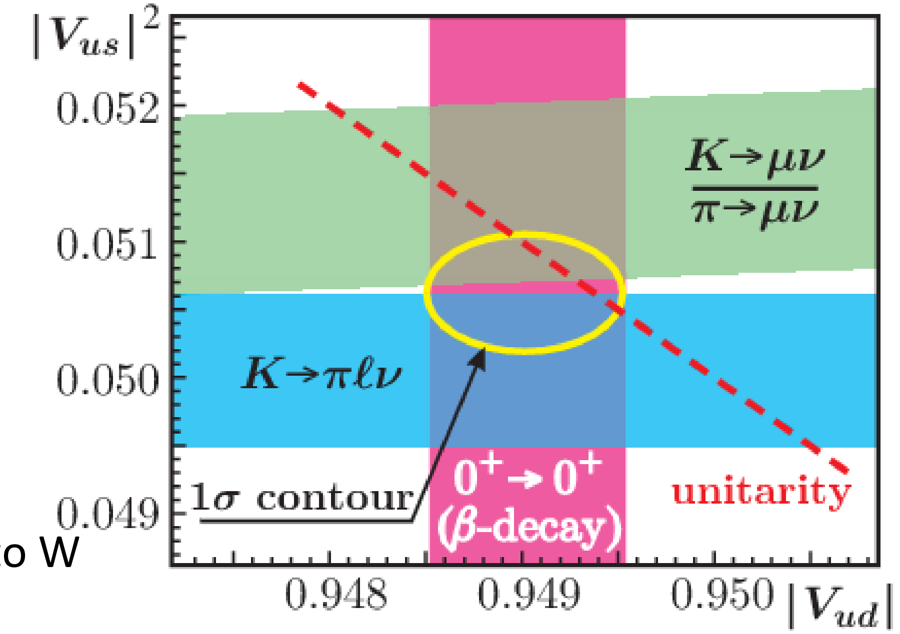
- Fit to $|V_{ud}|^2$, $|V_{us}|^2$ and $|V_{us}/V_{ud}|^2$

  JHEP 04 (2008)

  $|V_{ud}|^2 = 0.9490(5)$
  $|V_{us}|^2 = 0.0506(4)$
  $\chi^2 = 2.3/1$ (13%)

- Agreement with unitarity

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



- Universality of lepton and quark weak coupling to W

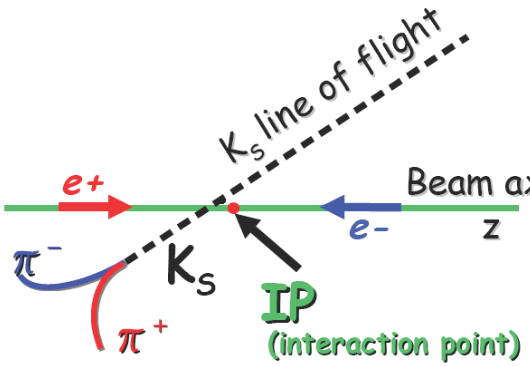
  $G_F = 1.166371(6)\times 10^{-5}$ GeV^{-2}

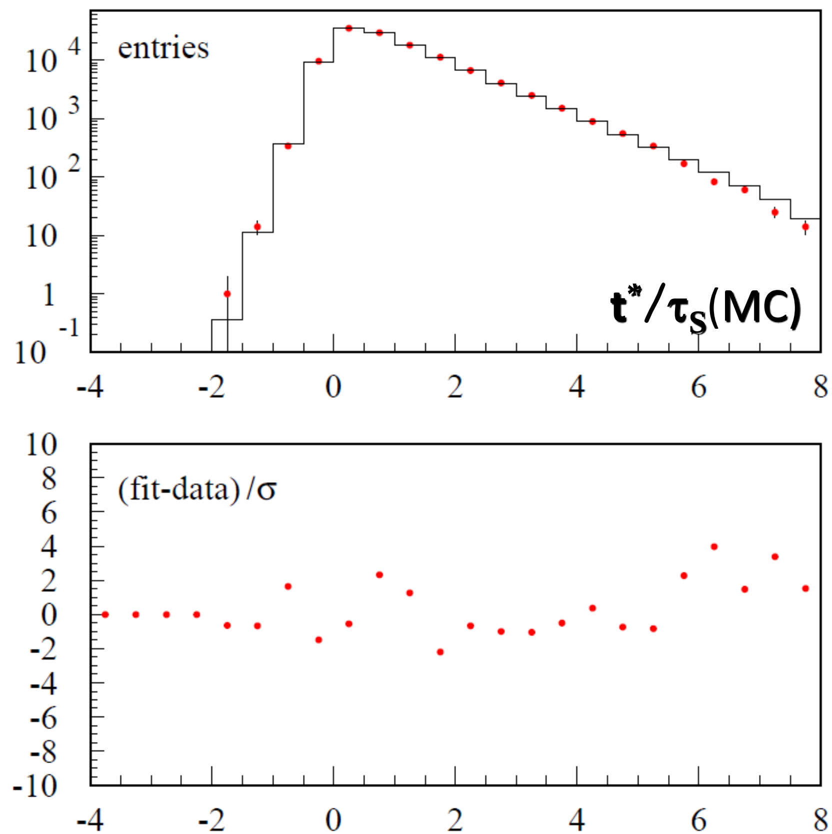
  $G_{CKM} = 1.16604(40)\times 10^{-5}$ GeV^{-2}

$$G_F^2 \equiv G_{CKM}^2 = (|V_{ud}|^2 + |V_{us}|^2) G_F^2$$

Ks Lifetime measurement (I)

- Lifetime from fit to proper time t^* distribution of $\mathbf{K_S} \rightarrow \pi^+\pi^-$ (18 million from '04 data)
- Event-by-event ϕ-meson decay point from PCA of K_L flight direction to beam line ($\sigma(Z_{IP})$= 0.2 cm while beam spread ~3 cm)
- Improve time resolution with kinematic fit (free x_{KS} and L_{KS}, K direction fixed)





- Fiducial volume: 18x10 [ϕ_K, cosθ_K] bins
  $-0.5 < \cos\theta_\pi < +0.5$
- Fit range: 15 bins from -1 to +6.5 in $\mathbf{t^*/\tau_S}$(MC)
- Fit function used in [ϕ_K, cosθ_K] bin

$$f(t) = A \int_{\infty}^{\infty} \theta(x) \frac{1}{\tau} \exp(x/\tau)\, \varepsilon(x)\, g(t+\delta-x)\, dx$$

- Performed ā total of 180 independent fits

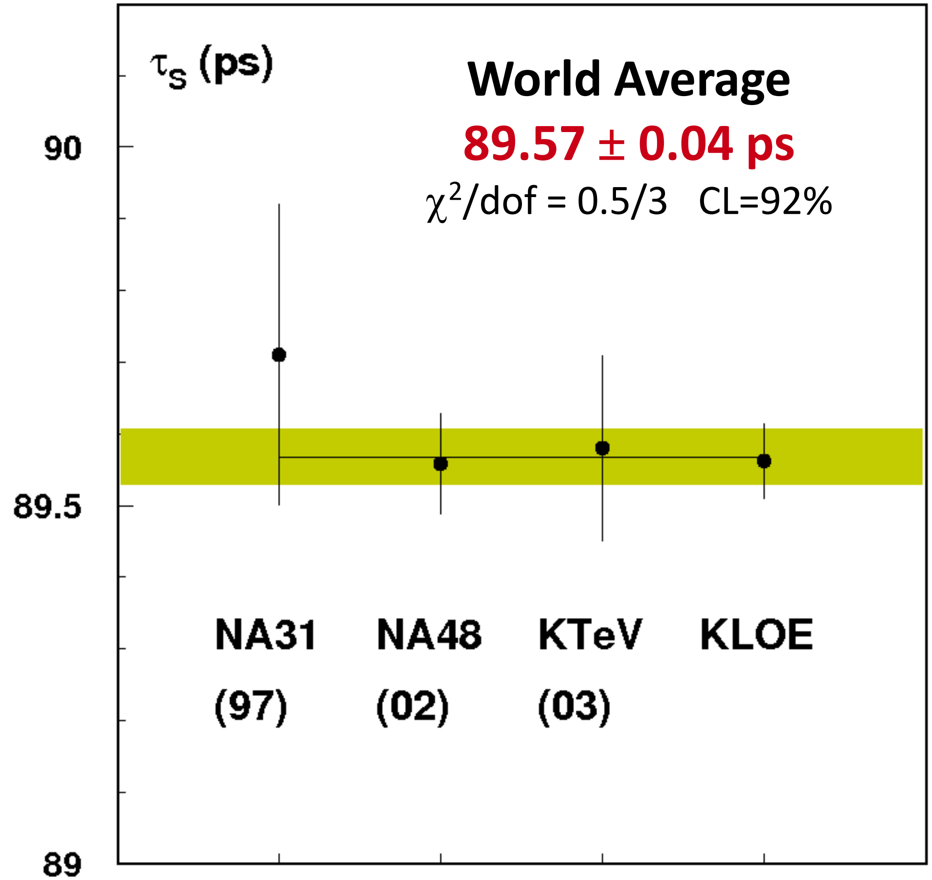
Ks Lifetime measurement (II)

First measurement with pure K_S beam and event by event knowledge of K_S momentum

$$\tau_S = (89.56 \pm 0.03_{stat} \pm 0.04_{syst})\ \text{ps}$$

0.06%

Systematics	Value (ps)
Fit range	0.012
Selection cuts	0.024
p_K calibration	0.033
Kaon mass	0.004
Efficiency(L_K)	0.005
Total	**0.043**



Paper in preparation

|Vus| f+ (0): present World Averages

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

			Approx. contr. to % err from:			
		% err	BR	τ	δ	$I_{K\ell}$
$K_L e3$	0.2163(6)	0.26	0.09	0.20	0.11	0.06
$K_L \mu3$	0.2166(6)	0.29	0.15	0.18	0.11	0.08
$K_S e3$	0.2155(13)	0.61	0.60	0.03	0.11	0.06
$K^\pm e3$	0.2160(11)	0.52	0.31	0.09	0.40	0.06
$K^\pm \mu3$	0.2158(14)	0.63	0.47	0.08	0.39	0.08

Experimental Inputs to be improved

From Flavianet Kaon WG arXiv:1005.2323v1

The KLOE-2 Project: Physics & Collider

❖ The KLOE-2 project aims at improving the successful and fruitful results achieved by the KLOE Collaboration in Kaon and Hadron Physics and extending the physics program to :

- $\gamma\gamma$-physics from $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- + X$
- search for particles from "hidden sectors" that might explain dark matter

Physics with the KLOE-2 experiment at the upgraded DAΦNE, EPJC 68,619 (2010)

❖The project will exploit the new interaction scheme implemented on the Frascati DAFNE phi-factory collider with the SIDDHARTA experiment in 2008/09 with:

- Larger beam crossing angle and crab-waist sextupoles
- Luminosity increase of a factor of ~3
- $\int$ Ldt ~ 1pb^{-1}/h and Max L=4.5x 10^{32} cm^{-2}s^{-1}

With the new configuration $\int$ Ldt ~5 fb^{-1}/y can be delivered

High Energy Proposal: upgrade in energy of the collider (from 1.02 GeV to 2.5 GeV)

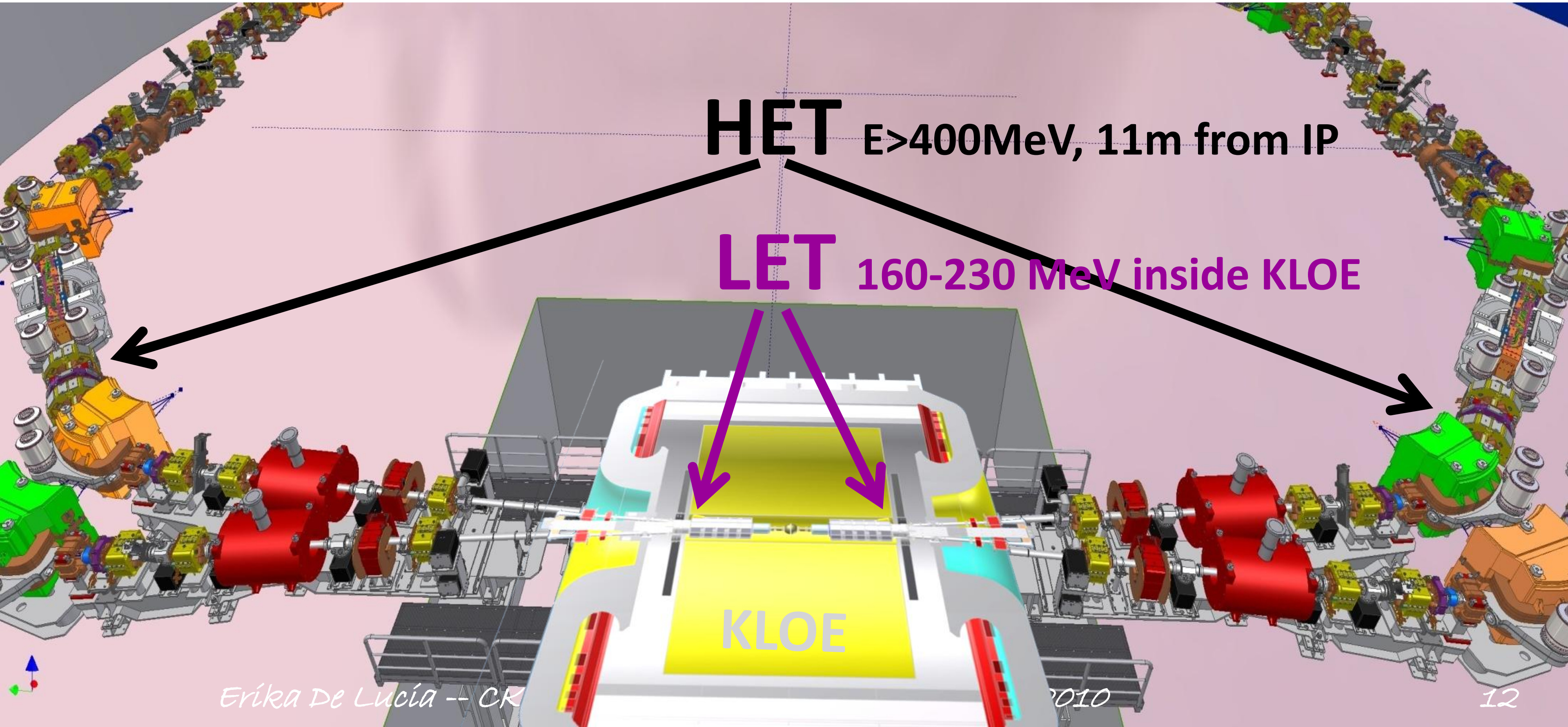
Proposal for taking data with the KLOE-2 Detector at the DAΦNE collider upgraded in energy, LNF-Note 10/17(P)

The KLOE-2 Project: detector upgrades

1st phase/step-0 now ($\int Ldt \sim 5\ fb^{-1}$):

LET & HET *Technical Design Report* ***LNF - 10/14(P)***

- ✓ LYSO+SiPMs & Scint+PMTs
- ✓ Lepton taggers for $\gamma\gamma$-physics



The KLOE-2 Project: detector upgrades

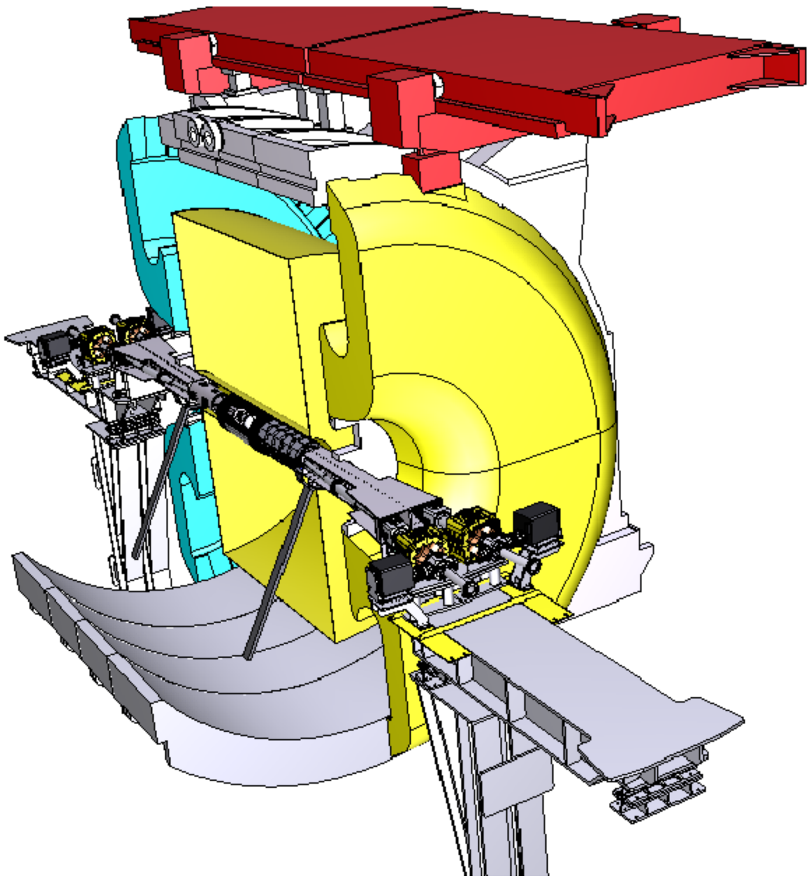
1st phase/step-0 now ($\int$Ldt ~ 5 fb^{-1}):

LET & HET *Technical Design Report* ***LNF - 10/14(P)***

✓ LYSO+SiPMs & Scint+PMTs

✓ Lepton taggers for $\gamma\gamma$-physics

2nd phase /step-1 late 2011 ($\int$Ldt ~ 20 fb^{-1}):



The KLOE-2 Project: detector upgrades

1st phase/step-0 now ($\int Ldt \sim 5\ fb^{-1}$):

LET & HET *Technical Design Report* ***LNF - 10/14(P)***

✓ LYSO+SiPMs & Scint+PMTs

✓ Lepton taggers for $\gamma\gamma$-physics

2nd phase /step-1 late 2011 ($\int Ldt \sim 20\ fb^{-1}$

CCAL

✓ LYSO + APD

✓ Increase acceptance for γ's from IP (21 →10)

INNER TRACKER *Technical Design Report - **arXiv:10***

✓ 4 layers of cylindrical triple GEM

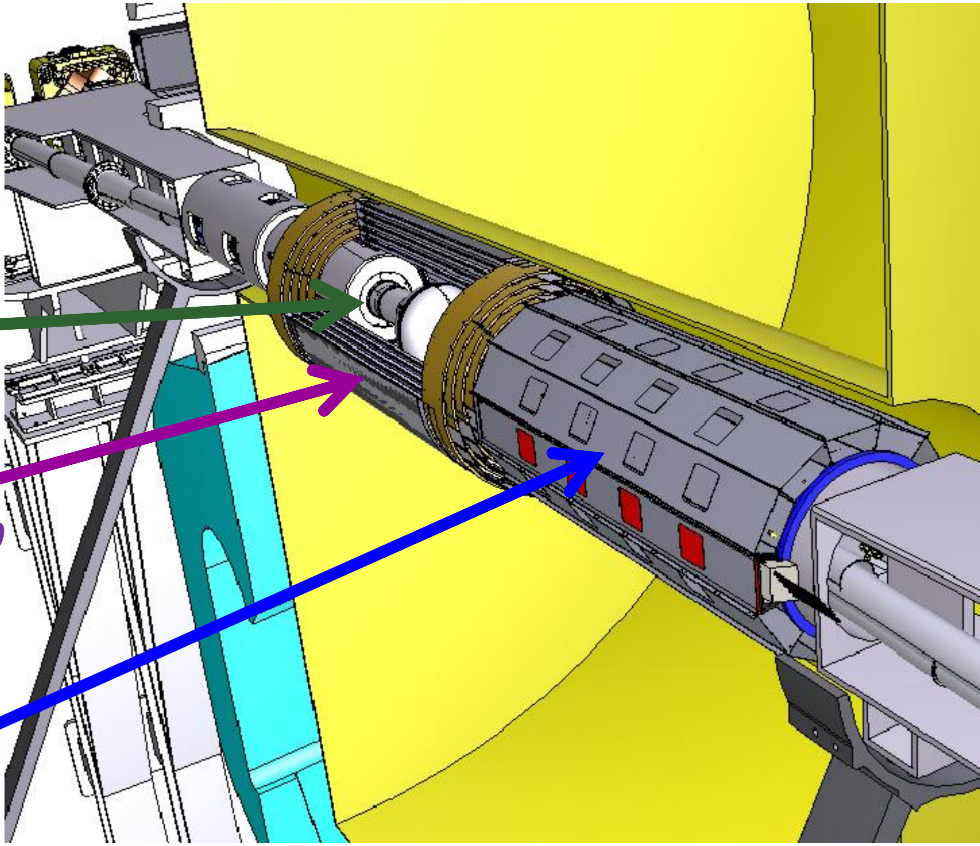
✓ Better vertex reconstruction near IP

✓ Larger acceptance for low pt tracks

QCALT

✓ W + scintillator tiles + SiPM/WLS

✓ quadrupoles coverage for K_L decays



The KLOE-2 Project: detector upgrades

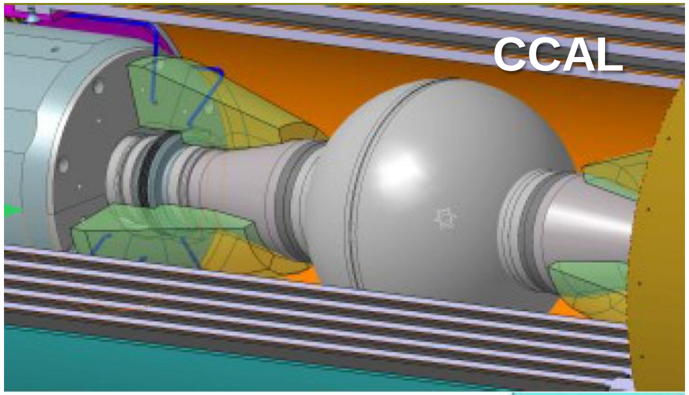
1st phase/step-0 now ($\int Ldt \sim 5\ fb^{-1}$):

LET & HET *Technical Design Report* ***LNF - 10/14(P)***

✓ LYSO+SiPMs & Scint+PMTs

✓ Lepton taggers for $\gamma\gamma$-physics

2nd phase /step-1 late 2011 ($\int Ldt \sim 20\ fb^{-1}$):



CCAL

✓ LYSO + APD

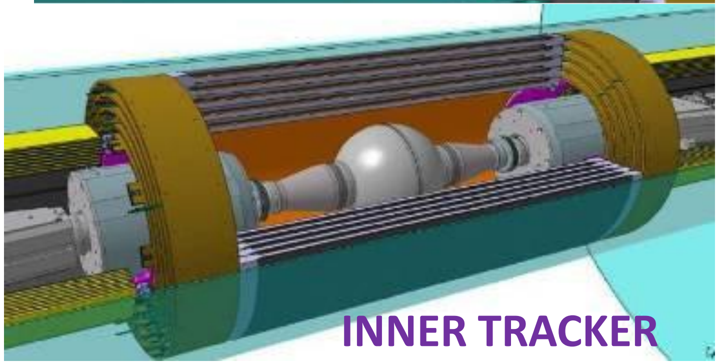
✓ Increase acceptance for γ's from IP
(21 →10)

INNER TRACKER *Technical Design Report -* ***arXiv:1002.2572***

✓ 4 layers of cylindrical triple GEM

✓ Better vertex reconstruction near IP

✓ Larger acceptance for low pt tracks

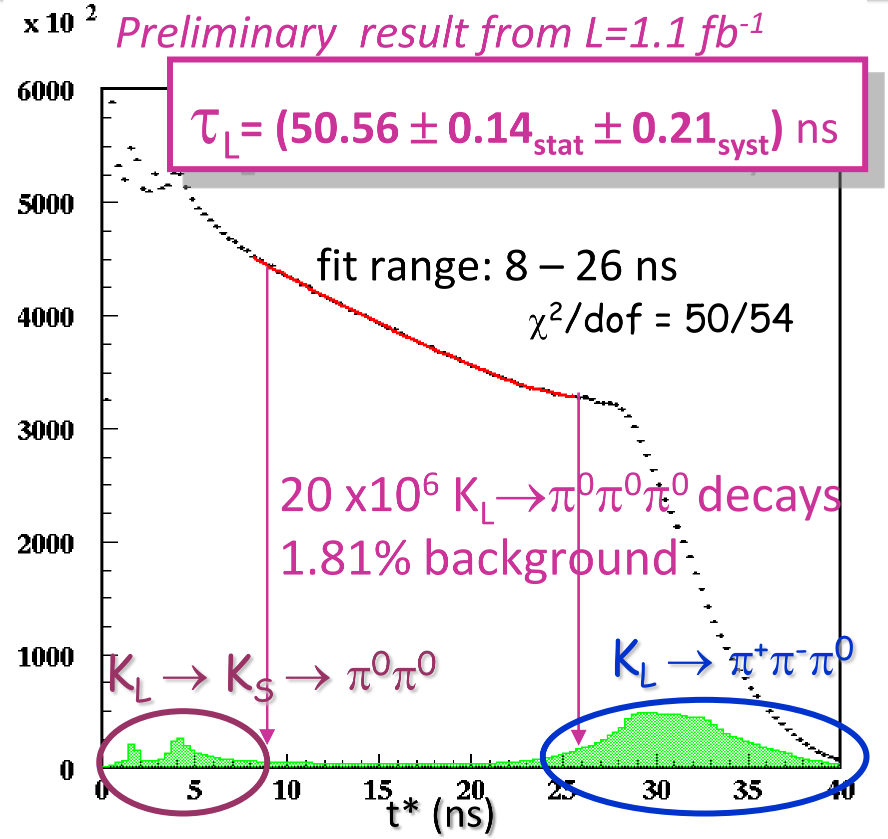


QCALT

✓ W + scintillator tiles + SiPM/WLS

✓ quadrupoles coverage for K_L decays

Improving $K_{L,S}$ & $K^{\pm}$ lifetime: $\tau_{L,S}, \tau_{\pm}$



i. 0.38% is expected with whole KLOE data
ii. 0.27% adding 5 fb^{-1} from KLOE-2/step-0
iii. < 0.2%. inserting QCALT improving photon reconstruction & control of the systematics

Systematic errors in KLOE are partially statistical in nature: efficiencies are measured with data control samples. Then also these contributions to the total uncertainty decrease with statistics

$\tau_{\pm}$

i. 0.1% is expected with KLOE + 5 fb^{-1} KLOE-2 /step-0
ii. x2 inserting Inner Tracker,allowing detection of $K^{\pm}$ tracks closer to the IP, improves accuracy of the decay length technique

τ_S

0.03% is expected adding 5 fb^{-1} from KLOE-2/step-0 .

Improving BRs & Form Factors

BR(Kse3)

i. 0.6% expected with KLOE + 5 fb^{-1} KLOE-2/step-0
ii. 0.3% with 25fb^{-1} and Inner Tracker: better tracking performance for decays close to IP in terms of acceptance and background rejection

Systematic errors in KLOE are partially statistical in nature: efficiencies are measured with data control samples. Then also these contributions to the total uncertainty decrease with statistics

BR(Ksμ3)

i. KLOE first experimental evidence, shows the potentiality of reaching <2% on BR with 2.5fb^{-1}
ii. 0.4% with KLOE-2 and Inner Tracker

Kaon Form Factors

K_L: x3 improvement with 5 fb^{-1} KLOE-2/step-0 with respect to the published results on the vector FF in KLe3 decays and the vector and scalar FF in KLμ3 decays

$K^{\pm}$: KLOE analysis just started, will profit from no ambiguities on lepton charge assignment and on π/μ identification (limiting factor on KLμ3 FFs)

$|V_{us}| f_+(0)$: future perspectives with KLOE (2.5 fb^{-1}) & KLOE-2/step0 (5 fb^{-1})

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

• Statistical uncertainties on BRs and lifetimes obtained scaling to 7.5 fb^{-1} total integrated luminosity

• Systematic errors: conservative estimate based on KLOE published analyses without improvements from the detector upgrade

World-average uncertainties for BR(K_Le3), δ and $I_{K\ell}$ from old **Flavianet paper arXiv:0801.1817v1**

			Approx. contr. to % err from:			
		% err	**BR**	τ	δ	$I_{K\ell}$
K_Le3	**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_Se3	**0.2153(7)**	**0.33**	**0.30**	0.03	**0.11**	0.09
$K^\pm e3$	**0.2152(8)**	**0.37**	**0.25**	0.05	**0.25**	0.09
$K^\pm\mu3$	**0.2132(9)**	**0.40**	**0.27**	0.05	**0.25**	0.15

Physics with the KLOE-2 experiment at the upgraded DAΦNE --EPJC 68,619 (2010)

$|V_{us}| f_+(0)$: future perspectives with KLOE (2.5 fb^{-1}) & KLOE-2/step0 (5 fb^{-1})

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

Using world-average uncertainties for BR(K_Le3), δ and $I_{K\ell}$ from **updated Flavianet paper** ***arXiv:1005.2323v1***

			Approx. contr. to % err from:			
		% err	**BR**	**τ**	**δ**	**$I_{K\ell}$**
K_Le3	**0.2155(4)**	**0.20**	0.09	**0.13**	**0.11**	0.06
$K_L\mu3$	**0.2167(4)**	**0.21**	0.10	**0.13**	**0.11**	0.08
K_Se3	**0.2153(7)**	**0.32**	**0.30**	0.03	**0.11**	0.06
$K^\pm e3$	**0.2152(10)**	**0.47**	**0.25**	0.05	**0.40**	0.06
$K^\pm\mu3$	**0.2132(10)**	**0.48**	**0.27**	0.05	**0.39**	0.08

$|V_{us}| f+(0)$: future perspectives with KLOE (2.5 fb^{-1}) & KLOE-2/step0 (5 fb^{-1})

❖KLOE-2 can significantly improve the accuracy on the measurement of K_L , $K^\pm$ lifetimes and K_Se3 branching ratio with respect to present world average with data from the first year of data taking, at KLOE-2/step-0.

❖The present 0.23% fractional uncertainty on |Vus| × f+(0) can be reduced to 0.14% using KLOE present data set together with the KLOE-2/step-0 statistics.

❖Detector upgrades have not been considered in this evaluation

	$f_+(0)V_{us}$
KLOE today *(World Average)*	**0.28%** (0.23%)
KLOE + Step-0 + WA	**0.14%**

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

$$\sigma(1-V_{ud}^2-V_{us}^2) = 6 \times 10^{-4} \begin{cases} V_{us} \text{ @ } 0.4\% \text{ from fit} \\ V_{ud} \text{ @ } 0.026\% \end{cases}$$

❖ To improve the accuracy on the V_{us} determination and then its contribution to the total uncertainty on the unitarity relation, a more precise estimate of $f_+(0)$ is needed.

Conclusions

Investigation at a ϕ–factory can shed light on several debated issues in particle physics

The KLOE collaboration achieved several precision Kaon Physics results

The KLOE-2 collaboration is ready to start a new enthusiastic data-taking campaign, to pursue a rich physics program

DAFNE commissioning is in progress

The present 0.23% fractional uncertainty on $|V_{us}| \times f_+(0)$ can be reduced to 0.14% using KLOE present data set together with the KLOE-2/step-0 statistics.