Status and prospects for Lorentz and CPT violation tests at KLOE and KLOE-2

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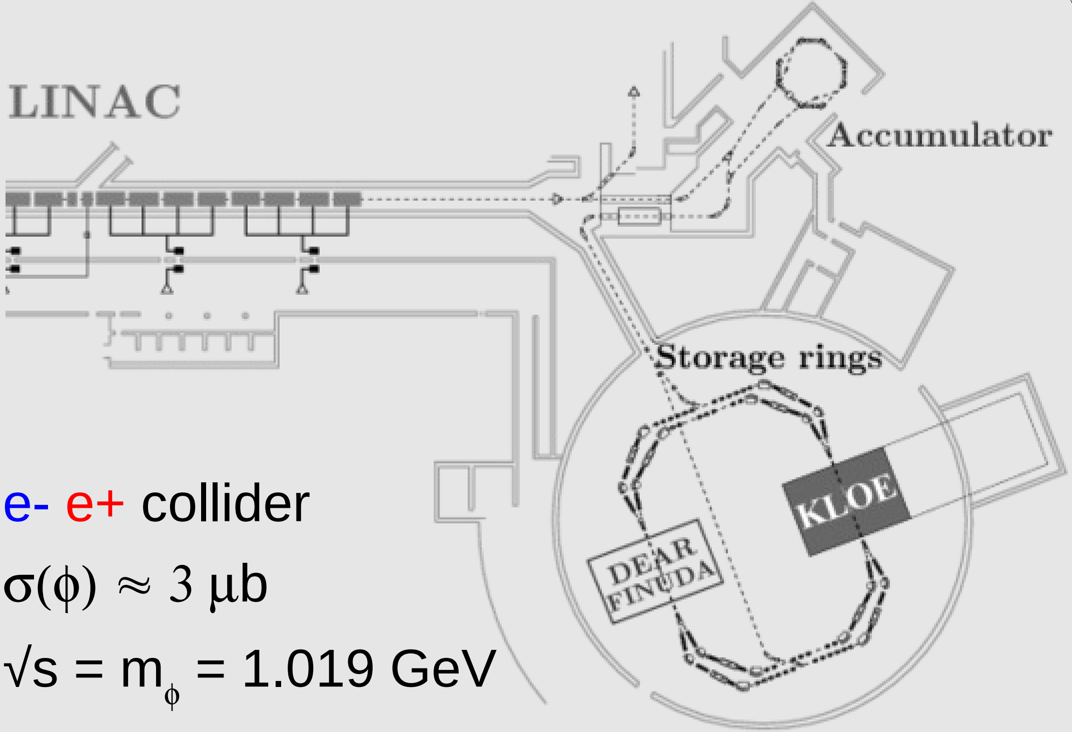
On behalf of the KLOE/KLOE-2 Collaboration

CPT'10: Fifth Meeting on
CPT AND LORENTZ SYMMETRY
Indiana University, Bloomington
June 28-July 2, 2010

DAFNE Facility at Frascati labs



e- e+ collider

$\sigma(\phi) \approx 3\ \mu b$

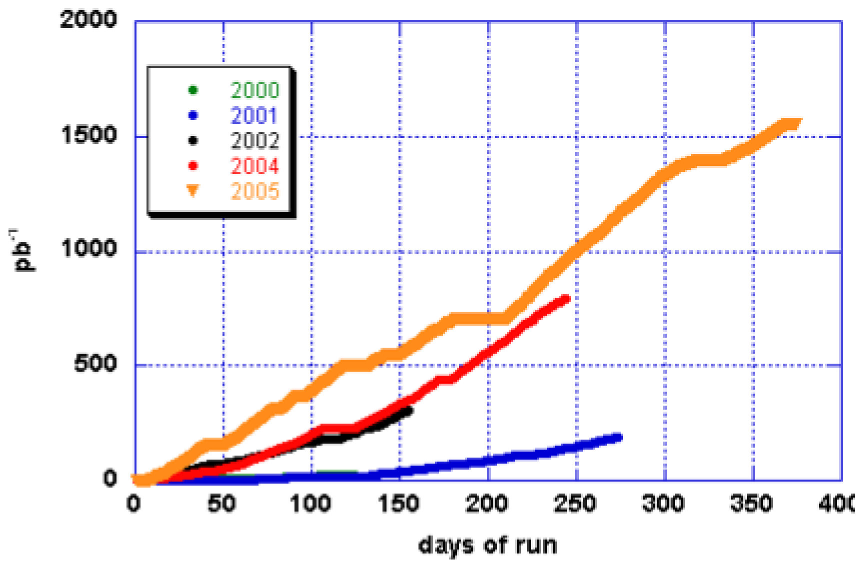
$\sqrt{s} = m_\phi = 1.019$ GeV

Low beam-beam interactions (2 rings)

2x15 mrad crossing angle ($p_x(\phi)$ ~15 MeV)

2 interaction regions (one for KLOE)

KLOE integrated luminosity



KLOE Data-taking periods:

- 2001-2002 $p_x(\phi)$ ~12 MeV
- 2004-2005 $p_x(\phi)$ ~15 MeV
- 2006 $\sqrt{s}$ =1.0 GeV

The KLOE detector

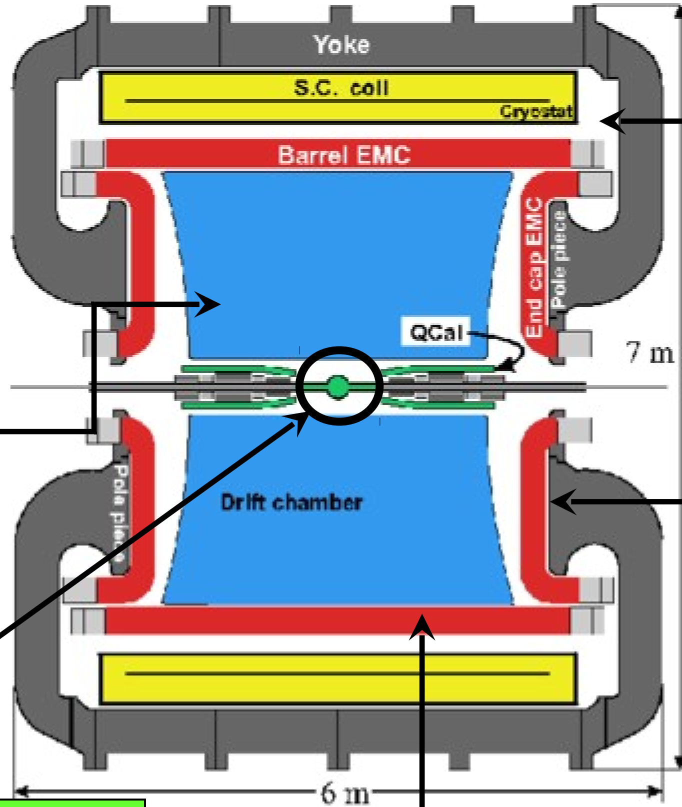
Drift Chamber

$\sigma_p/p \cong 0.4\ \%$

(tracks with $\theta > 45°$)

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

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



SC Magnet

B = 0.52 T

End Cap

Calorimeter e.m.

Both side read-out (PM)

$\sim 4\pi$ solid angle coverage

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

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

Barrel

Interaction point (IP)

Sphere Al-Be (Ø 10 cm)

Physics at KLOE: kaons

ϕ meson decays mostly in pair of kaons (BR ~83%).
A big fraction is neutral (K_0 $\bar{K}_0$ BR ~34%)

Initial state is composed by correlated pair of neutral kaons

$$|\phi\rangle = \frac{1}{\sqrt{2}}\{|K_0(\vec{p})\rangle|\bar{K}_0(-\vec{p})\rangle - |K_0(-\vec{p})\rangle|\bar{K}_0(\vec{p})\rangle\}$$

The eigenvector for the Hamiltonian of the Kaon are not flavour eigenvector

$$|K_{S,L}\rangle = N\{(1+\epsilon_{S,L})|K_0\rangle \pm (1-\epsilon_{S,L})|\bar{K}_0\rangle\}$$

CP violation

SME in correlated kaon system

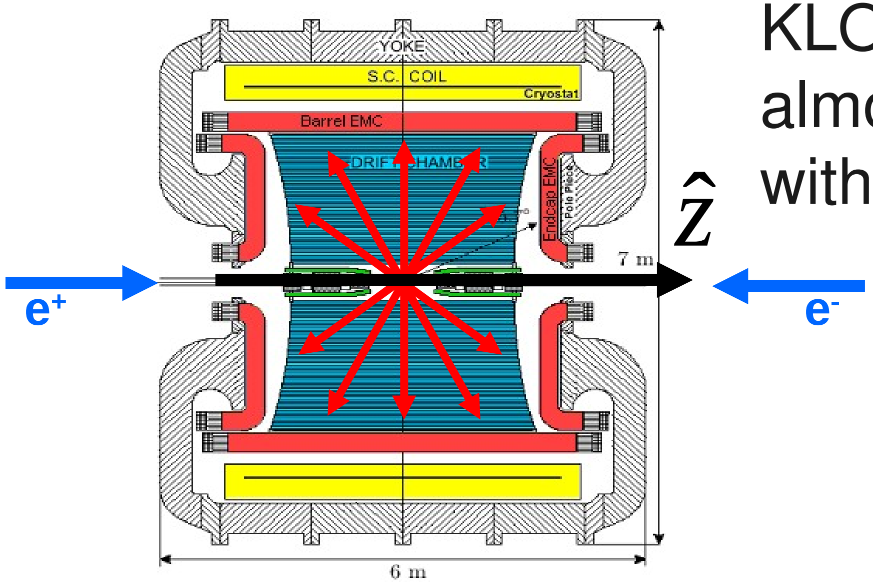
Kostelecky et al. developed a theoretical possibility for CPT violation based on spontaneous breaking of CPT and Lorentz symmetry, which might happen at Planck scale. It appears to be compatible with the basic tenets of quantum field theory, and retains the property of gauge invariance and renormalizability (Standard Model Extension - SME)
[Kostelecky PRD61 (1999) 016002, PRD 64 (2001) 076001]

CPT violation in SME manifests to lowest order in δ (the direct CPT violation parameters vanish at first order) and exhibits a kaon momentum dependence:

$$\varepsilon_{S,L} = \varepsilon \pm \delta \qquad \delta = i \sin\phi_{SW} e^{i\phi_{SW}} \gamma_K \left(\Delta a_0 - \vec{\beta}_K \cdot \Delta\vec{a} \right) / \Delta m$$

where Δa_μ are four parameters associated to SME lagrangian terms and related to CPT and Lorentz violation.

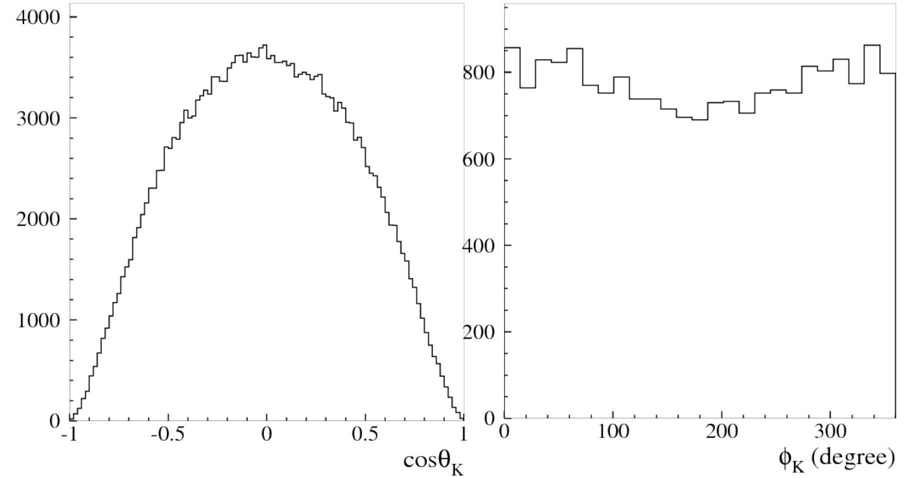
Possibility for a ϕ factory



KLOE is a telescope able to observe almost any direction of the space with his kaon beam.

At DAΦNE K mesons are emitted with angular distribution $dN/d\Omega \propto \sin^2\theta$

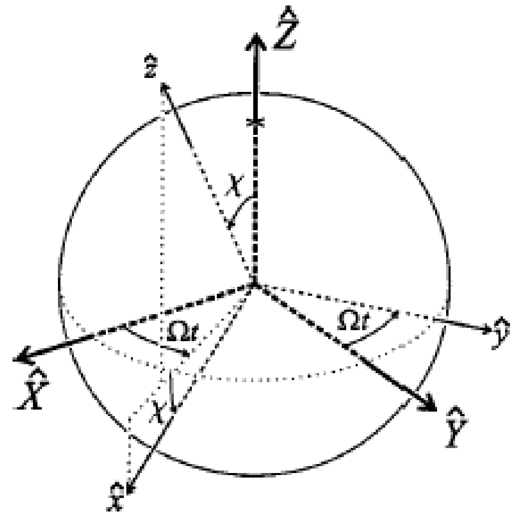
KLOE is efficient in all angles



KLOE lat	~41.8°
KLOE lon	~12.7°
Z axis	~S57.8°W

SME induced CPTV: space-time dependence

δ depends on sidereal time t since laboratory frame rotates with Earth (fixed beam).
For a ϕ-factory there is an additional dependence on the polar and azimuthal angle θ, ϕ of the kaon momentum in the laboratory frame:



$$\delta(\vec{p}_K, t) = \frac{i \sin\phi_{SW} e^{i\phi_{SW}}}{\Delta m}$$
$$\gamma_K \{\Delta a_0 + \beta_K \Delta a_Z (\cos\vartheta \cos\chi - \sin\vartheta \cos\phi \sin\chi)$$
$$-\beta_K \Delta a_X \sin\vartheta \sin\phi \sin\Omega t$$
$$+\beta_K \Delta a_X (\cos\vartheta \sin\chi + \sin\vartheta \cos\phi \sin\chi) \cos\Omega t$$
$$+\beta_K \Delta a_Y (\cos\vartheta \sin\chi + \sin\vartheta \cos\phi \sin\chi) \sin\Omega t$$
$$-\beta_K \Delta a_Y \sin\vartheta \sin\phi \cos\Omega t\}$$

Ω: Earth's sidereal frequency
χ : angle between the z lab. axis and the Earth's rotation axis

CPTV measurements method

Possible methods to measure Δa_μ at KLOE

(1) Semileptonic asymmetries of K_S and K_L

(a) Δa_0 from $A_S - A_L$

(b) Δa_{XYZ} from A_L

(2) Interferometry with $\phi \to K_S K_L \to \pi^+\pi^- \pi^+\pi^-$

(3) Interferometry with $\phi \to K_S K_L \to \pi l \nu \; \pi l \nu$

(1) Kaon Semileptonic asymmetry

$$A_{S,L} = \frac{\Gamma\left(K_{S,L} \to \pi^- e^+ \nu\right) - \Gamma\left(K_{S,L} \to \pi^+ e^- \bar{\nu}\right)}{\Gamma\left(K_{S,L} \to \pi^- e^+ \nu\right) + \Gamma\left(K_{S,L} \to \pi^+ e^- \bar{\nu}\right)}$$

$$= 2\Re\varepsilon \pm 2\Re\delta - 2\Re y \pm 2\Re x_-$$

By integrating over sidereal time,
polar and azimutal angles
Only the scalar term give contribution

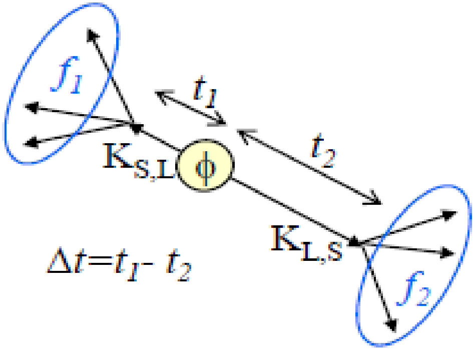
Δa_0 from K_S and K_L semileptonic charge asymmetries

$$A_S - A_L \propto \delta(\vec{p}_K, t) \longrightarrow A_S - A_L \cong \frac{4\Re\left(i \sin\phi_{SW} e^{i\phi_{SW}}\right)\gamma_K}{\Delta m}\Delta a_0$$

with L=400 pb^{-1} (**preliminary**): $\Delta a_0 = (0.4 \pm 1.8) \times 10^{-17}$ GeV

with L= 2.5 fb^{-1} we estimate:
$\sigma(\Delta a_0) \sim 7 \times 10^{-18}$ GeV

Kaon interferometry: basic principles

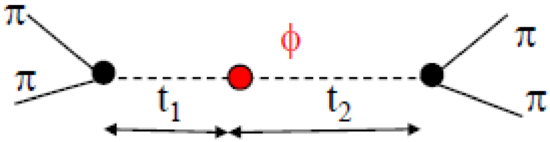


$$|i\rangle = \frac{1}{\sqrt{2}}\left[\left|K^0(\vec{p})\right\rangle\left|\bar{K}^0(-\vec{p})\right\rangle - \left|\bar{K}^0(\vec{p})\right\rangle\left|K^0(-\vec{p})\right\rangle\right]$$
$$= \frac{N}{\sqrt{2}}\left[\left|K_S(\vec{p})\right\rangle\left|K_L(-\vec{p})\right\rangle - \left|K_L(\vec{p})\right\rangle\left|K_S(-\vec{p})\right\rangle\right]$$

$$I(f_1, f_2; \Delta t) = \frac{\Gamma_S^1 \Gamma_S^2}{2\Gamma} e^{-\Gamma|\Delta t|}\left[|\eta_1|^2 e^{\frac{\Delta\Gamma}{2}\Delta t} + |\eta_2|^2 e^{-\frac{\Delta\Gamma}{2}\Delta t} - 2\Re e\left(\eta_1 \eta_2 e^{-i\Delta m \Delta t}\right)\right]$$

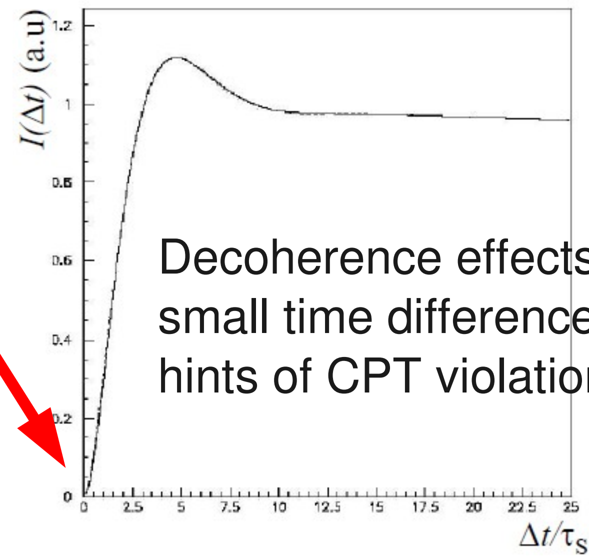
Assuming same final state: $\pi^+\pi^-$

$\Delta t = |t_1 - t_2|$



EPR correlation:

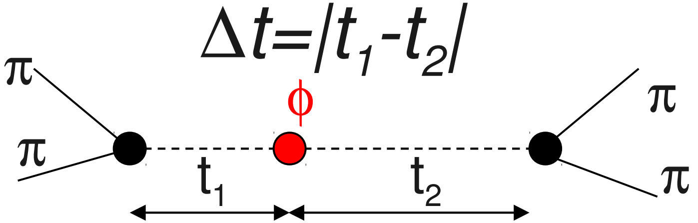
no simultaneous decays (Δt=0) in the same final state due to the destructive quantum interference

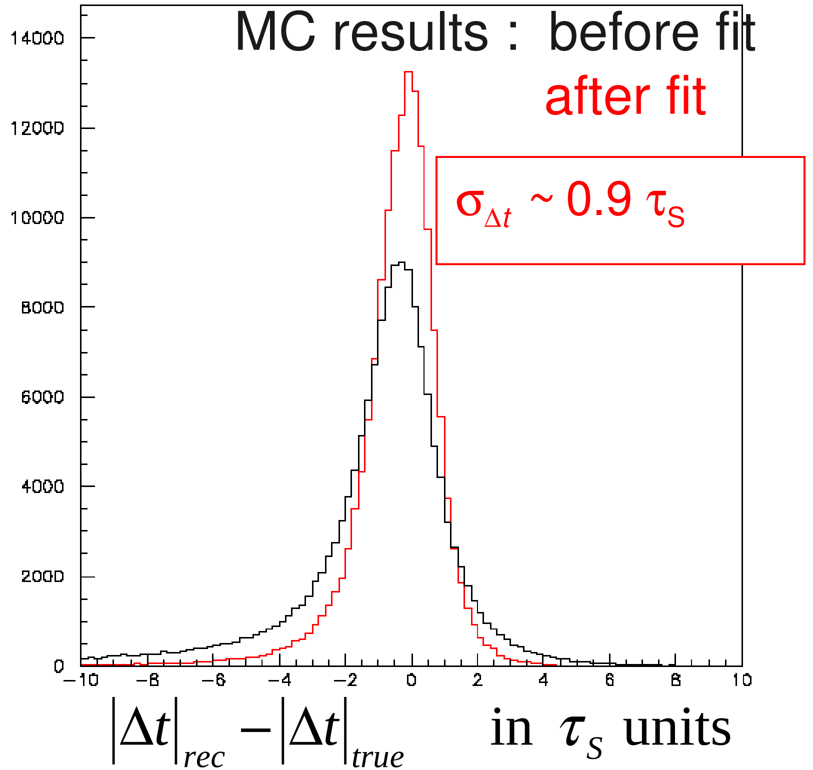


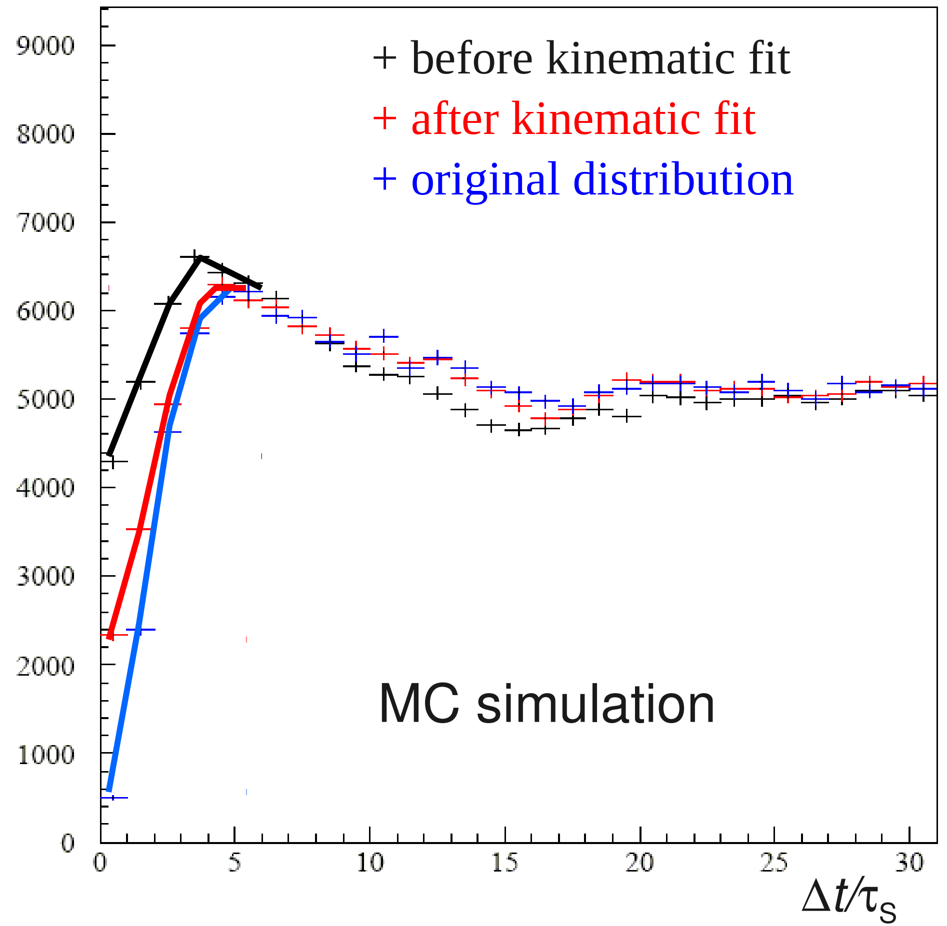
Decoherence effects at small time difference are hints of CPT violation.

(2) Kaon interferometry: improving Δt resolution

A kinematic fit is performed to improve the vertex and Δt resolution:



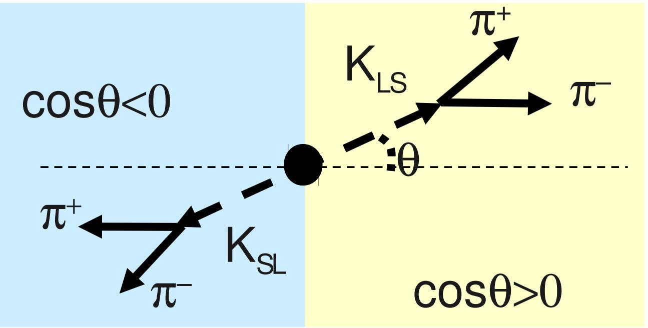




(2) Kaon interferometry: first approach

$\Delta a_{X,Y,Z}$ **from** $\phi \to K_S K_L \to \pi^+\pi^- \pi^+\pi^-$

(analysis vs polar angle θ and sidereal time t)



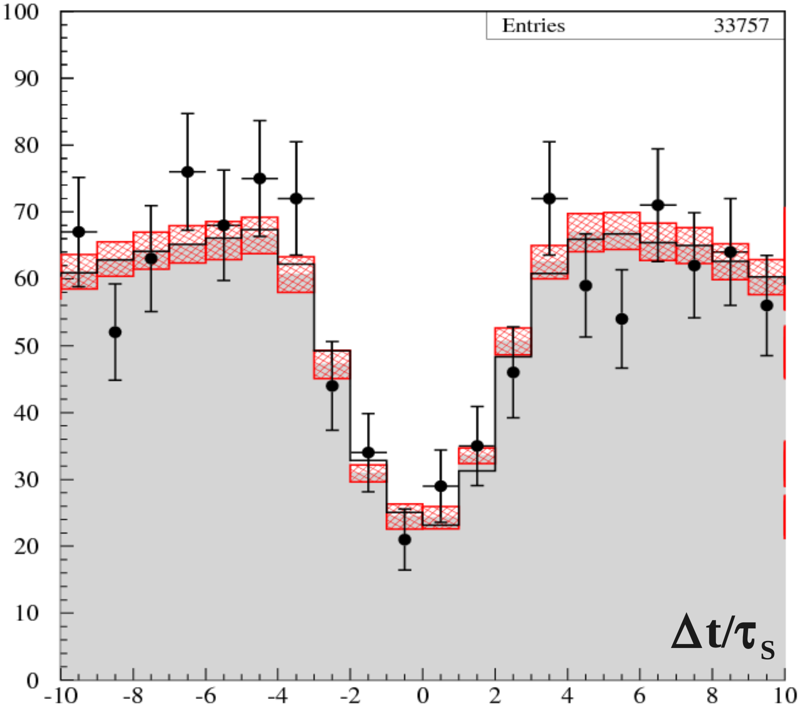
$$\eta_{+-} = \varepsilon - \delta(p, \theta, t)$$

with L=1 fb^{-1} (**preliminary**):

$$\Delta a_X = (-6.3 \pm 6.0) \times 10^{-18}\ \text{GeV}$$

$$\Delta a_Y = (2.8 \pm 5.9) \times 10^{-18}\ \text{GeV}$$

$$\Delta a_Z = (2.4 \pm 9.7) \times 10^{-18}\ \text{GeV}$$

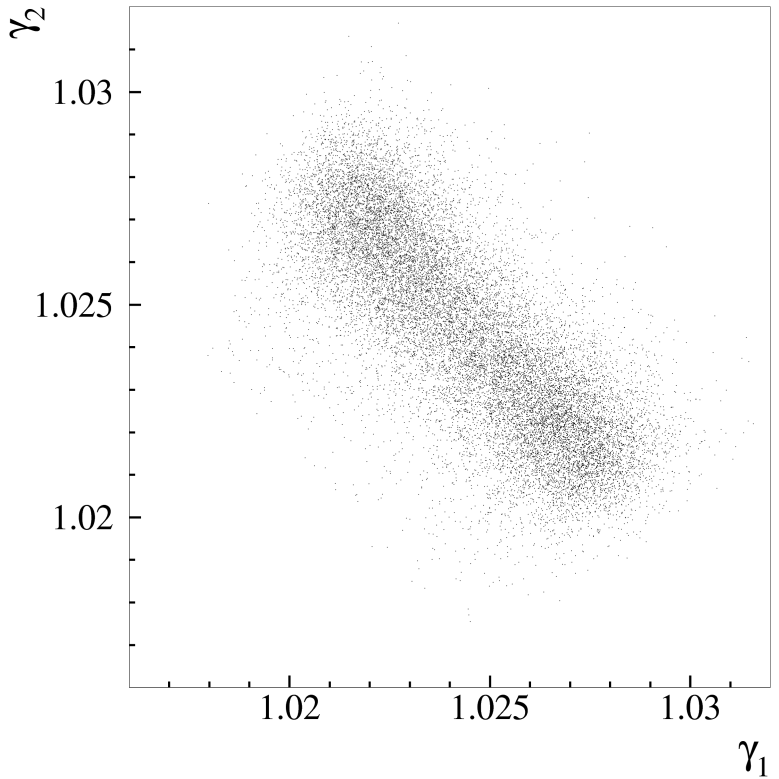


KTeV : Δa_X, $\Delta a_Y < 9.2 \times 10^{-22}$ GeV @ 90% CL

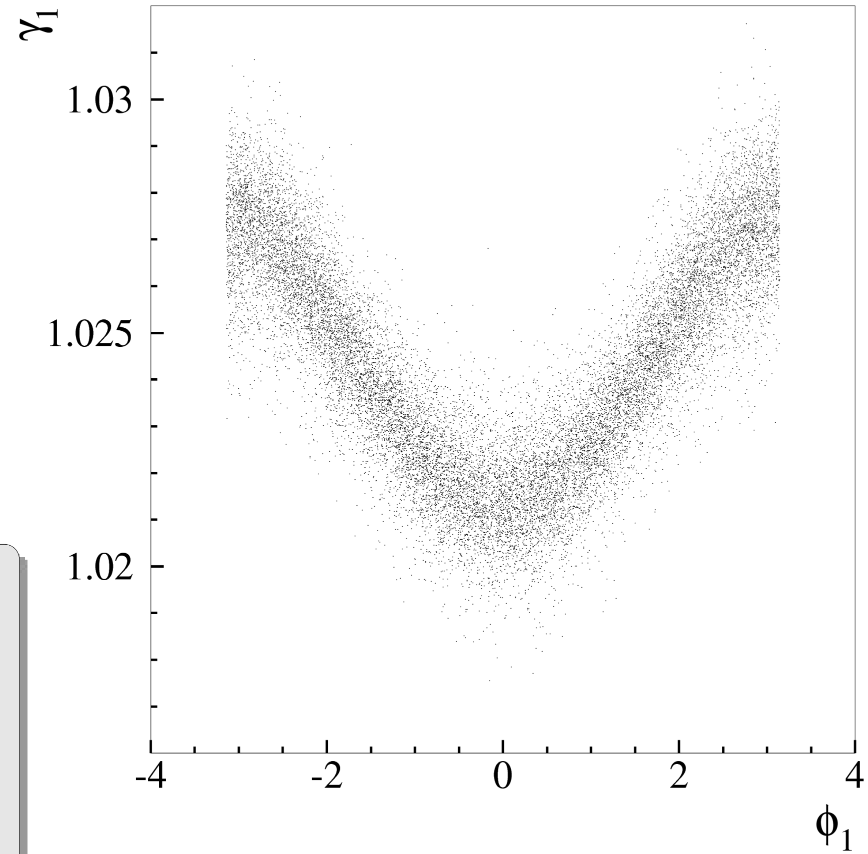
BABAR Δa^B_{xy} , $(\Delta a^B_0 - 0.30\ \Delta a^B_Z) \sim O(10^{-13}$ GeV)

[PRL 100 (2008) 131802]

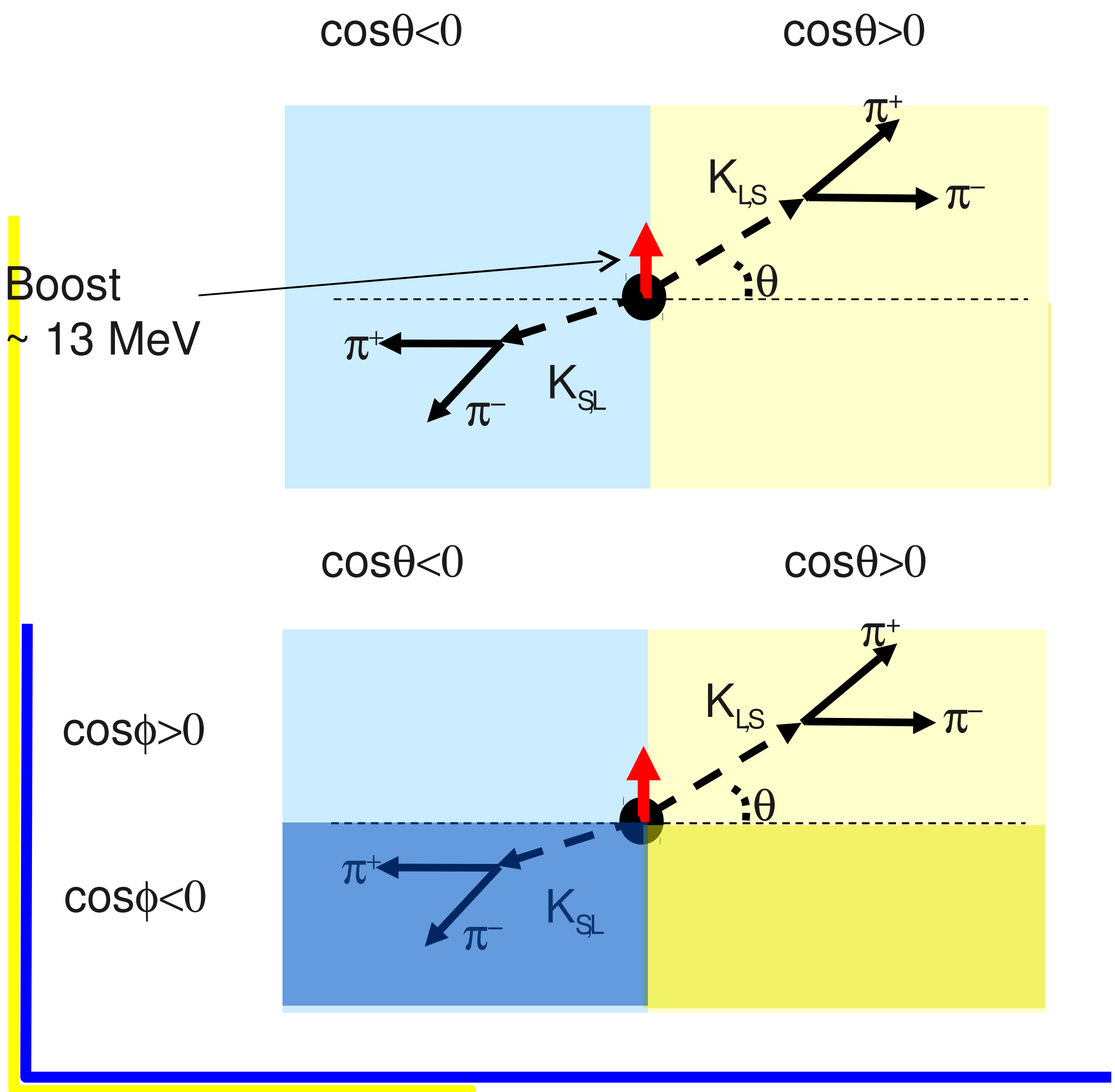
(2) Kaon interferometry: new approach



At DAFNE ϕ is produced with small momentum along x this implies that kaons are boosted in the lab frame. The boost is correlated to the direction of the kaon



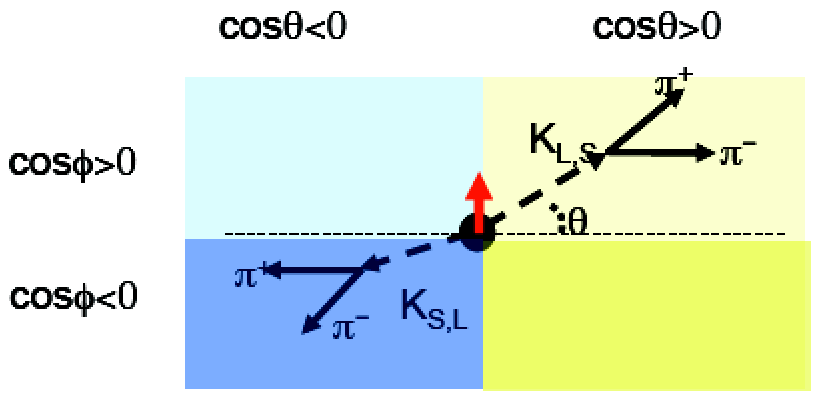
(2) The boost opportunity



Possible effects due to $\Delta a_0(\sim\gamma_K)$ are washed out in the simple forward (cosθ>0) - backward (cosθ<0) analysis

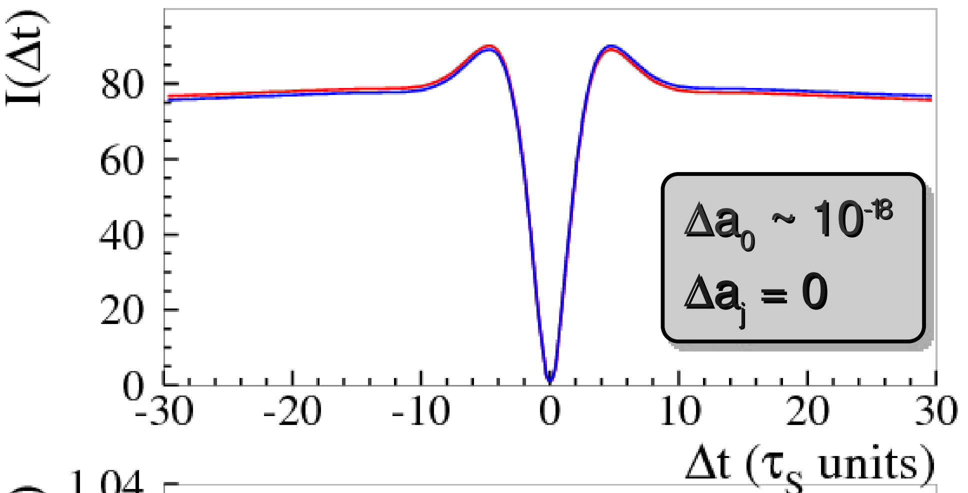
while could be present in the quadrant (cosθ>0 cosφ>0) - (cosθ<0 cosφ<0) analysis

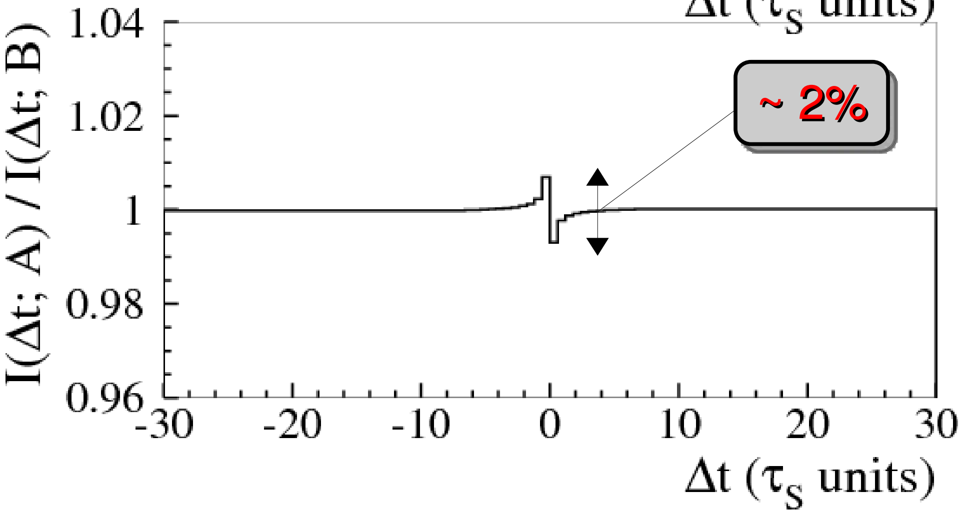
(2) New approach: sensitivity



Using the quadrant analysis and putting all parameters to zero except for the scalar, we could observe asymmetries up to percent level on the scalar term.

Analysis with this method ongoing
First result for the end of the year

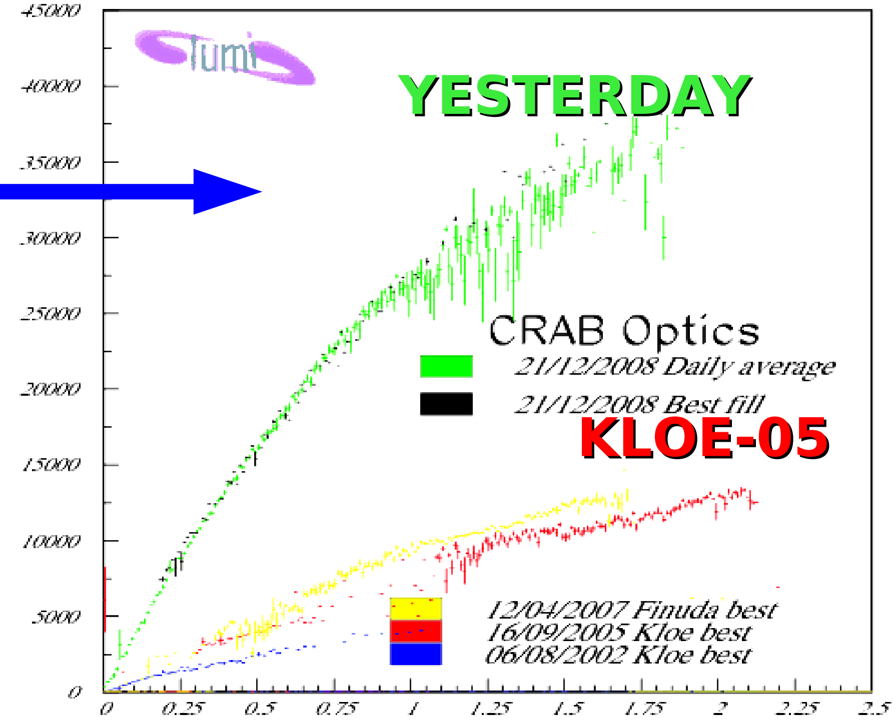




KLOE-2/step0: prospects on CPTV analysis

New machine magnetic scheme:
CRAB WAIST
Big improvement in luminosity (**x3**) with same beam currents

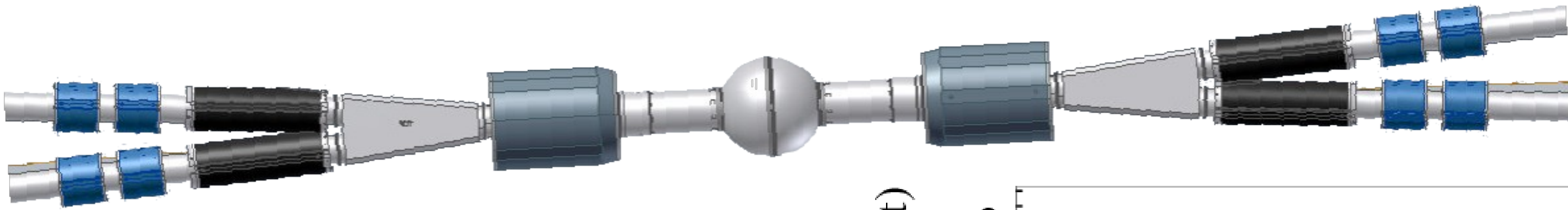
Future **DATA TAKING** plans:
STEP-0[2010]: $5fb^{-1}$
(double KLOE stat)
Taggers for γγ physics



Beam currents

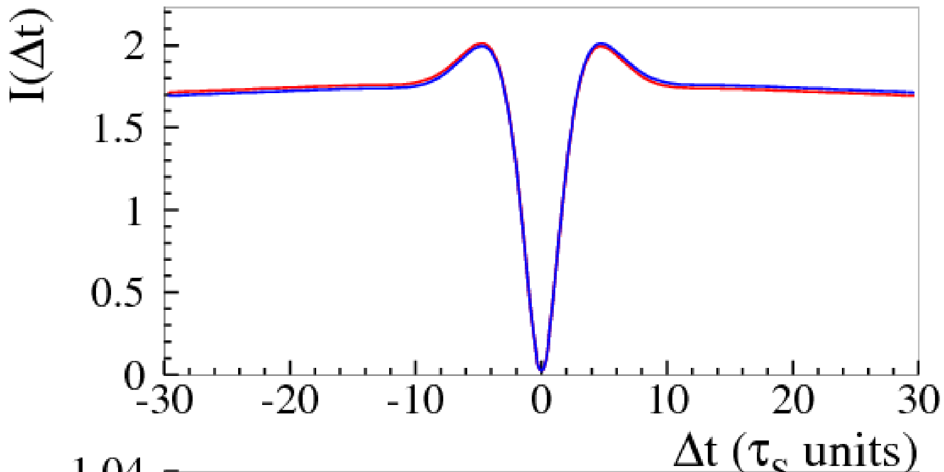
New interaction region scheme
Larger crossing angle

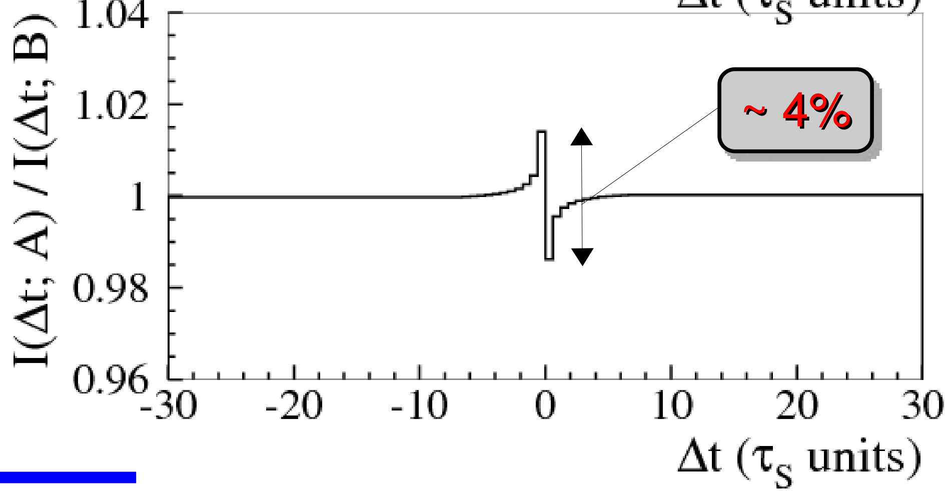
KLOE-2/step0: prospects on LV



Larger ϕ boost in the x direction

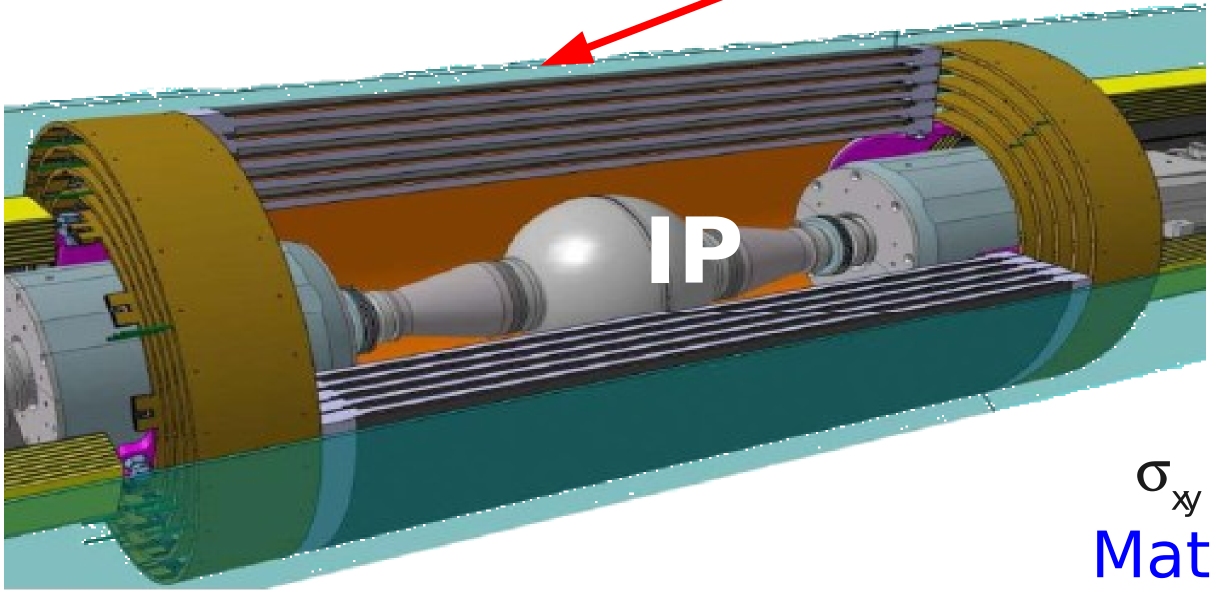
Increased sensitivity to Δa_0





KLOE-2 Step 1

TRIPLE Cylindrical GEM



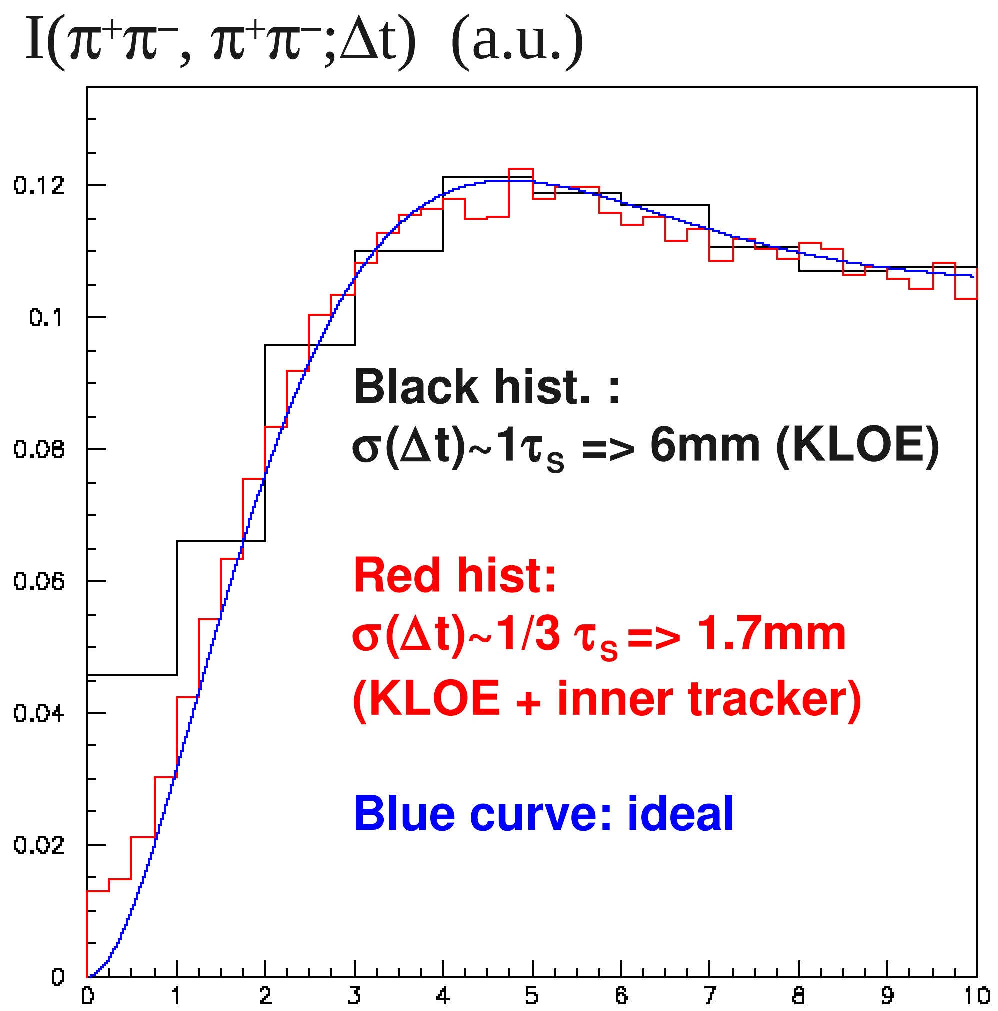
Inner Tracker

4 GEM planes
Min radius: 13 cm
Max radius: 25 cm
σ_{xy} ~ 200μm σ_z~ 500 μm
Material budget: **0.02 X_0**
Vertex resolution @IP increase: x3

Also in the STEP1:
CCALT: Crystal calorimeter near IP to <u>increase the angular acceptance</u>
QCALT: Tile calorimeter to <u>increase the hermiticity</u>

KLOE-2/step1: improvement on resolution

During the step-1 the kaon interferometry will benefit from **increased statistics** (**x4**) and also from **improved resolution** (**x3**) in the vertex reconstruction



Reconstructed distribution (MC)

- KLOE can use three methods to measure independently all four Δa_μ parameters

- From KLOE data we have a complete set of preliminary results

- Refined interferometric analysis method with the process $\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$ is ongoing

- KLOE-2 data-taking campaign is starting

- KLOE-2 expected improvements (IR + IT+ 25 fb^{-1}):
  - $\sigma\Delta a_0$ $O(10^{-19})$
  - $\sigma\Delta a_j$ $O(10^{-20})$

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THE EUROPEAN PHYSICAL JOURNAL C

Review

EPJC in press

Physics with the KLOE-2 experiment at the upgraded DAΦNE

Contents

1 Introduction

This report results from discussion started at the workshop held at the Frascati Laboratory of INFN to review the major topics of interest for investigation at the upgraded ϕ factory DAΦNE . The scientific program with a high-performance detector such as KLOE covers several fields in particle physics: from measurements of interest for the development of the Effective Field Theory (EFT) in quark-confinement regime to fundamental tests of Quantum Mechanics (QM) and CPT invariance. It includes precision measurements to probe lepton universality, CKM unitarity and settle the hadronic vacuum polarization contribution to the anomalous magnetic moment of the muon and to the fine structure constant at the M_Z scale.

During year 2008 the Accelerator Division of the Frascati Laboratory has tested a new interaction scheme on the DAΦNE ϕ-factory collider, with the goal of reaching a peak luminosity of 5×10^{32} cm^{-2}s^{-1}, a factor of three larger than what previously obtained. The test has been successful and presently DAΦNE is delivering up to 15 pb^{-1}/day, with solid hopes to reach soon 20 pb^{-1}/day [1,2]. Following these achievements, the data-taking campaign of the KLOE detector on the improved machine that was proposed in 2006 [3], will start in 2010.

KLOE is a multipurpose detector, mainly consisting of a large cylindrical drift chamber with an internal radius of 25 cm and an external one of 2 m, surrounded

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