Precision tests of CPT symmetry and Quantum coherence with entangled neutral K mesons in the search for Quantum Gravity effects

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Testing CPT: introduction

The three discrete symmetries of QM, C (charge conjugation: q → -q), P (parity: x → -x), and T (time reversal: t → -t) are known to be violated in nature both singly and in pairs. Only CPT appears to be an exact symmetry of nature.

CPT theorem holds for any QFT formulated on flat space-time which assumes: (1) Lorentz invariance (2) Locality (3) Unitarity (i.e. conservation of probability).

Extension of CPT theorem to a theory of quantum gravity far from obvious.
(e.g. CPT violation appears in several QG models)
huge effort in the last decades to study and shed light on QG phenomenology
⇒ Phenomenological CPTV parameters to be constrained by experiments

Consequences of CPT symmetry: equality of masses, lifetimes, |q| and |μ| of a particle and its anti-particle.

Neutral meson systems offer unique possibilities to test CPT invariance; e.g. taking as figure of merit the fractional difference between the masses of a particle and its anti-particle:

neutral K system	neutral B system	proton- anti-proton
$\left\|m_{K^0} - m_{\overline{K}^0}\right\| / m_K < 10^{-18}$	$\left\|m_{B^0} - m_{\overline{B}^0}\right\| / m_B < 10^{-14}$	$\left\|m_p - m_{\overline{p}}\right\| / m_p < 10^{-8}$

Other interesting CPT tests: e.g. the study of anti-hydrogen atoms, etc..

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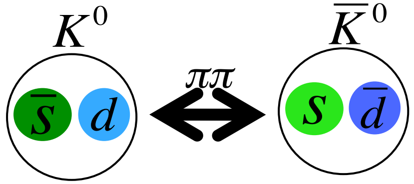
The neutral kaon system: introduction

The time evolution of a two-component state vector $|\Psi\rangle = a|K^0\rangle + b|\overline{K}^0\rangle$ in the $\{K^0, \overline{K}^0\}$ space is given by (Wigner-Weisskopf approximation):

$$i\frac{\partial}{\partial t}\Psi(t) = \mathbf{H}\Psi(t)$$



H is the effective hamiltonian (non-hermitian), decomposed into a Hermitian part (mass matrix **M**) and an anti-Hermitian part (i/2 decay matrix $\mathbf{\Gamma}$) :

$$\mathbf{H} = \mathbf{M} - \frac{i}{2}\mathbf{\Gamma} = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{21} & \Gamma_{22} \end{pmatrix}$$

Diagonalizing the effective Hamiltonian:

eigenvalues

$$\lambda_{S,L} = m_{S,L} - \frac{i}{2}\Gamma_{S,L}$$

$$|K_{S,L}(t)\rangle = e^{-i\lambda_{S,L}t}|K_{S,L}(0)\rangle$$

τ_S ~ 90 ps $\quad\tau_L$ ~ 51 ns

$K_L \rightarrow \pi\pi$ violates CP

eigenstates: physical states

$$|K_{S,L}\rangle = \frac{1}{\sqrt{2\left(1+|\varepsilon_{S,L}|\right)}}\left[\left(1+\varepsilon_{S,L}\right)|K^0\rangle \pm \left(1-\varepsilon_{S,L}\right)|\overline{K}^0\rangle\right]$$

$$= \frac{1}{\sqrt{\left(1+|\varepsilon_{S,L}|\right)}}\left[|K_{1,2}\rangle + \varepsilon_{S,L}|K_{2,1}\rangle\right]$$

$|K_{1,2}\rangle$ are CP=±1 states

$$\langle K_S|K_L\rangle \cong \varepsilon_S^* + \varepsilon_L \neq 0$$

small CP impurity ~2 x 10^{-3}

CPT violation: standard picture

CP violation:

$$\varepsilon_{S,L} = \varepsilon \pm \delta$$

T violation:

$$\varepsilon = \frac{H_{12} - H_{21}}{2\left(\lambda_S - \lambda_L\right)} = \frac{-i\Im M_{12} - \Im\Gamma_{12}/2}{\Delta m + i\Delta\Gamma / 2}$$

CPT violation:

$$\delta = \frac{H_{11} - H_{22}}{2\left(\lambda_S - \lambda_L\right)} = \frac{1}{2}\frac{\left(m_{\bar{K}^0} - m_{K^0}\right) - (i/2)\left(\Gamma_{\bar{K}^0} - \Gamma_{K^0}\right)}{\Delta m + i\Delta\Gamma/2}$$

- $\delta \neq 0$ implies CPT violation
- $\varepsilon \neq 0$ implies T violation
- $\varepsilon \neq 0$ or $\delta \neq 0$ implies CP violation

(with a phase convention $\Im\Gamma_{12} = 0$)

$$\Delta m = m_L - m_S \quad , \quad \Delta\Gamma = \Gamma_S - \Gamma_L$$

$$\Delta m = 3.5 \times 10^{-15} \text{ GeV}$$

$$\Delta\Gamma \approx \Gamma_S \approx 2\Delta m = 7 \times 10^{-15} \text{ GeV}$$

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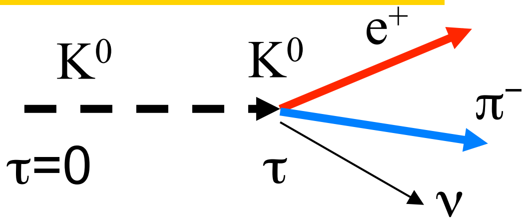
“Standard” CPT tests

"Standard" CPT test

Comparing "survival" probabilities of K^0 and $\bar{K}^0$ measuring semileptonic decays vs time: $\Re\delta = (3.0 \pm 3.3 \pm 0.6) \times 10^{-4}$



CPLEAR
PLB444 (1998) 52

using the unitarity constraint
(**Bell-Steinberger** relation) →

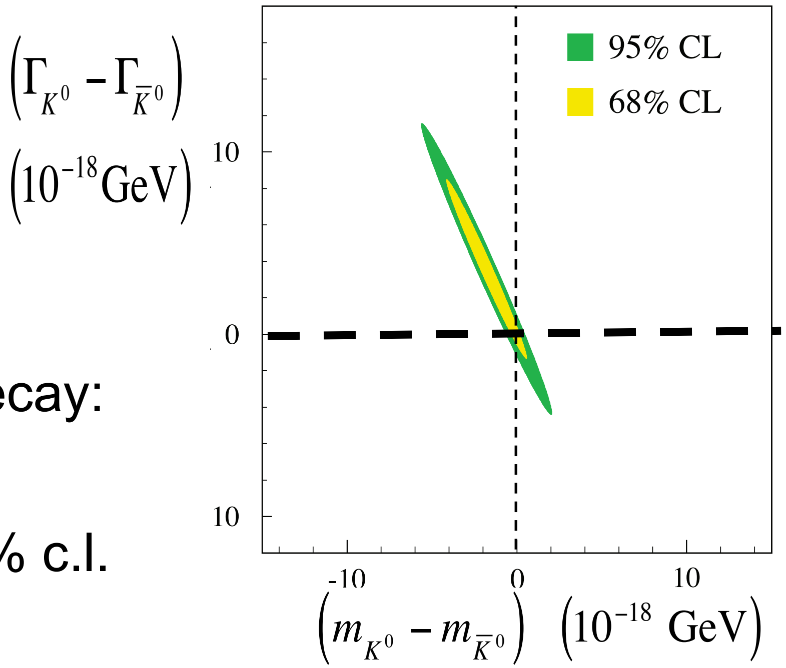
$$2\Im\delta = \Im\left[\langle K_L | K_S \rangle\right] = \Im\left[\frac{\sum_f \langle f|T|K_S\rangle \langle f|T|K_L\rangle^*}{i\left(\lambda_S - \lambda_L^*\right)}\right]$$

$\text{Im}\,\delta = (-0.7 \pm 1.4) \times 10^{-5}$

PDG fit (2014)

$$\delta = \frac{1}{2}\frac{\left(m_{\bar{K}^0} - m_{K^0}\right) - (i/2)\left(\Gamma_{\bar{K}^0} - \Gamma_{K^0}\right)}{\Delta m + i\Delta\Gamma/2}$$

Combining Reδ and Imδ results →



Assuming $\left(\Gamma_{\bar{K}^0} - \Gamma_{K^0}\right) = 0$, i.e. no CPT viol. in decay:

$$\left|m_{\bar{K}^0} - m_{K^0}\right| < 4.0 \times 10^{-19}\ \ \text{GeV}$$

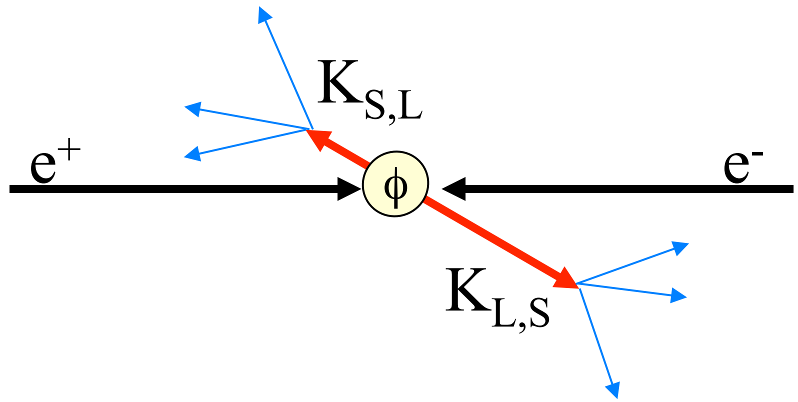
at 95% c.l.

Entangled neutral kaon pairs

Neutral kaons at a ϕ-factory

Production of the vector meson ϕ in e^+e^- annihilations:

- $e^+e^- \to \phi$ $\sigma_\phi \sim 3\ \mu b$
  $W = m_\phi = 1019.4$ MeV
- $BR(\phi \to K^0\bar{K}^0) \sim 34\%$
- $\sim 10^6$ neutral kaon pairs per pb^{-1} produced in an antisymmetric quantum state with $J^{PC} = 1^{--}$:



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

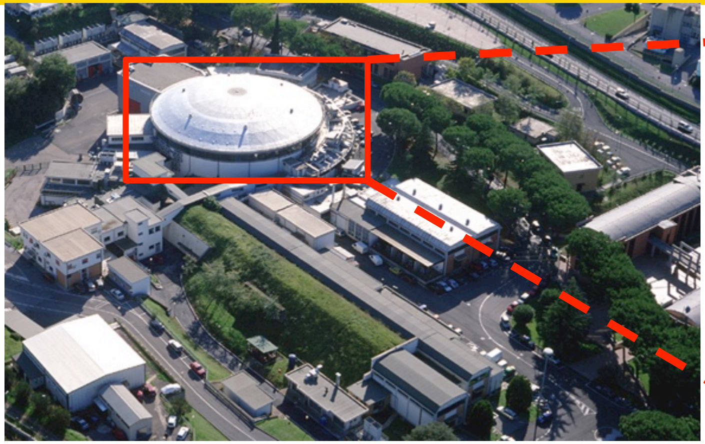
$$= \frac{N}{\sqrt{2}}\left[\left|K_S(\vec{p})\right\rangle\left|K_L(-\vec{p})\right\rangle - \left|K_L(\vec{p})\right\rangle\left|K_S(-\vec{p})\right\rangle\right]$$

$$N = \sqrt{\left(1+|\varepsilon_S|^2\right)\left(1+|\varepsilon_L|^2\right)} \Big/ \left(1-\varepsilon_S\varepsilon_L\right) \cong 1$$

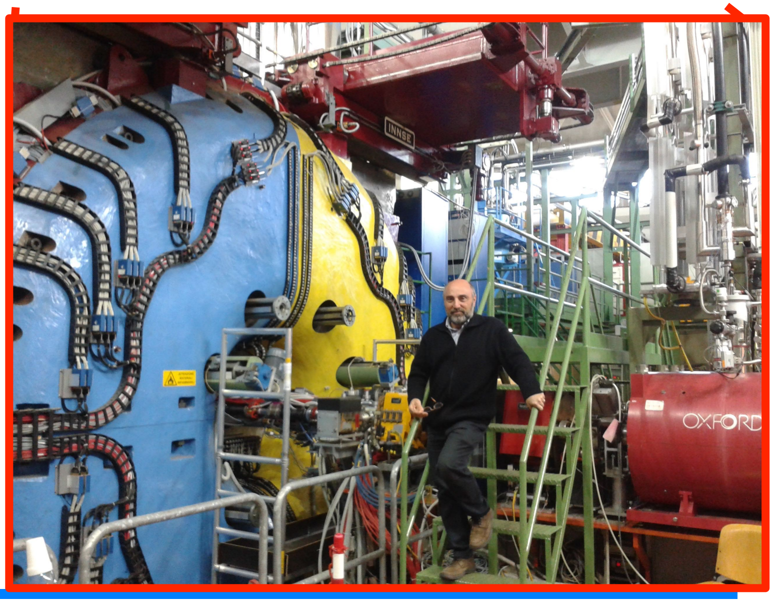
$p_K = 110$ MeV/c
$\lambda_S = 6$ mm $\lambda_L = 3.5$ m

The KLOE detector at the Frascati φ-factory DAΦNE

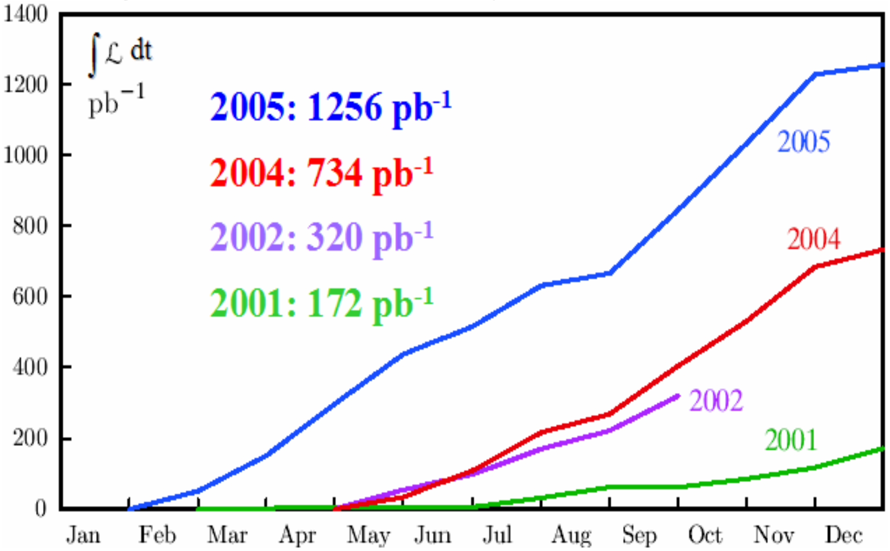
DAFNE collider



KLOE detector



Integrated luminosity (KLOE)



Total KLOE $\int\mathcal{L}\,dt \sim 2.5\ \mathrm{fb}^{-1}$
(2001 - 05) $\rightarrow \sim 2.5\times10^{9}\ K_S K_L$ pairs

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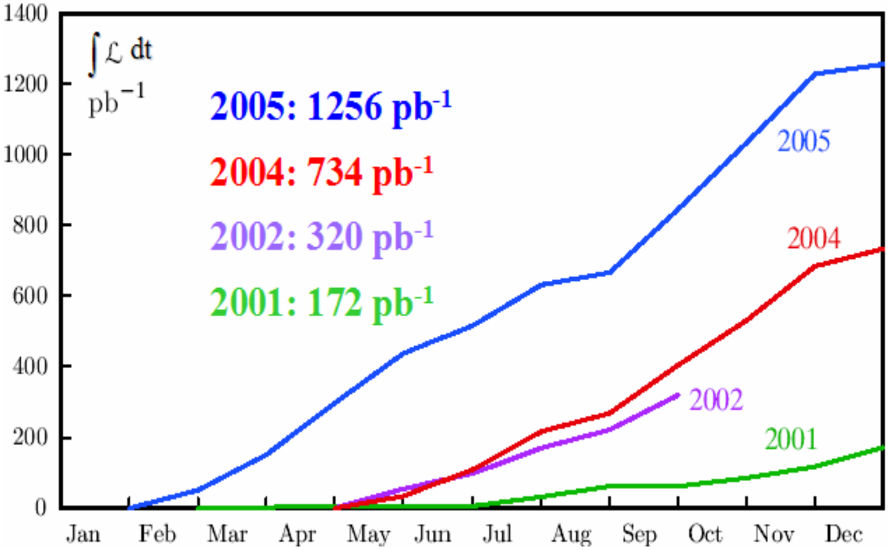

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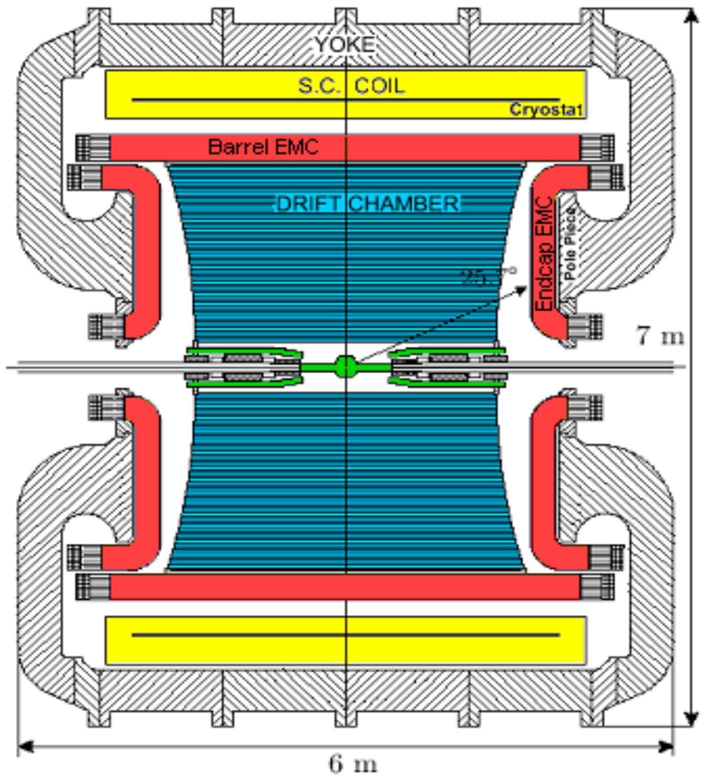

Lead/scintillating fiber calorimeter

drift chamber

4 m diameter × 3.3 m length

helium based gas mixture

Test of Quantum Coherence

EPR correlations in entangled neutral kaon pairs from φ

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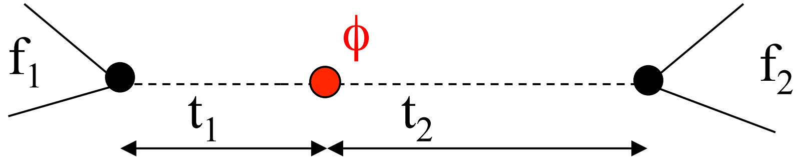

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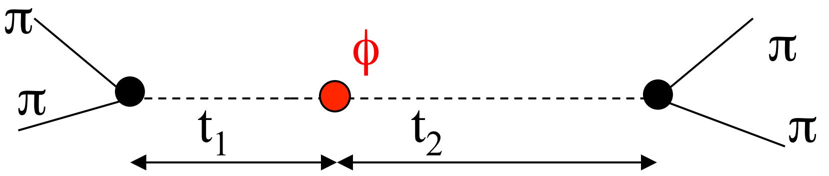

Same final state for both kaons: $f_1 = f_2 = \pi^+\pi^-$
(this specific channel is suppressed by CP viol.
$|\eta_{+-}|^2 = |A(K_L \to \pi^+\pi^-)/A(K_S \to \pi^+\pi^-)|^2 \sim |\varepsilon|^2 \sim 10^{-6}$)

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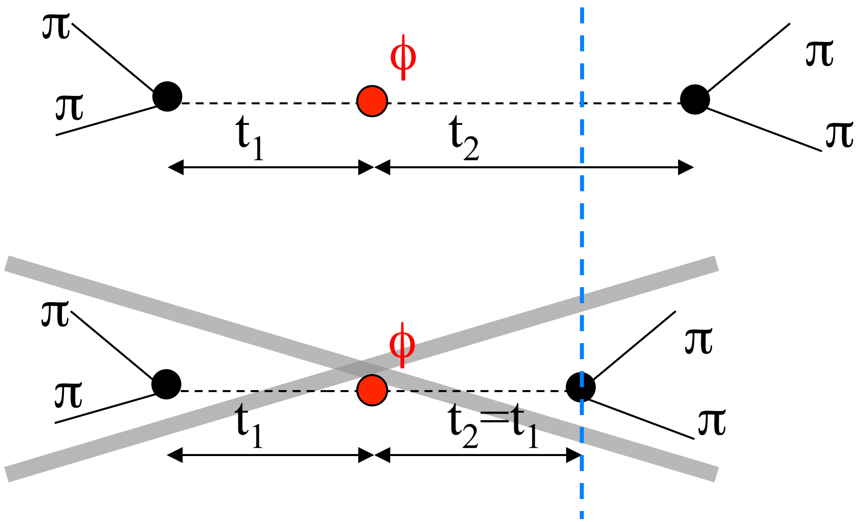

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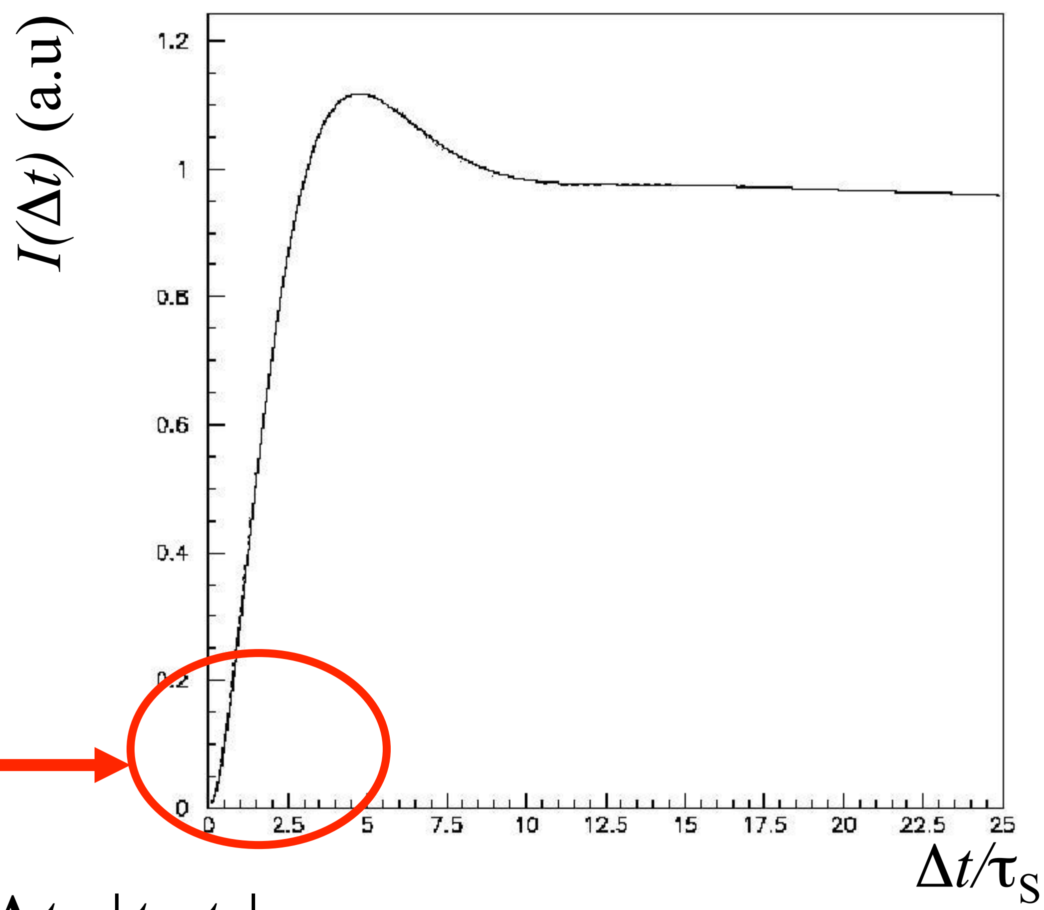

EPR correlation:

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

$\Delta t = |t_1 - t_2|$

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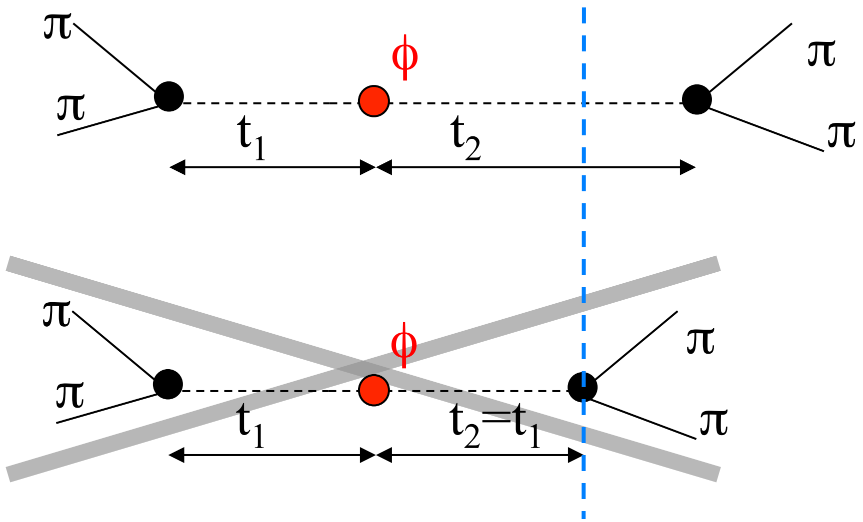

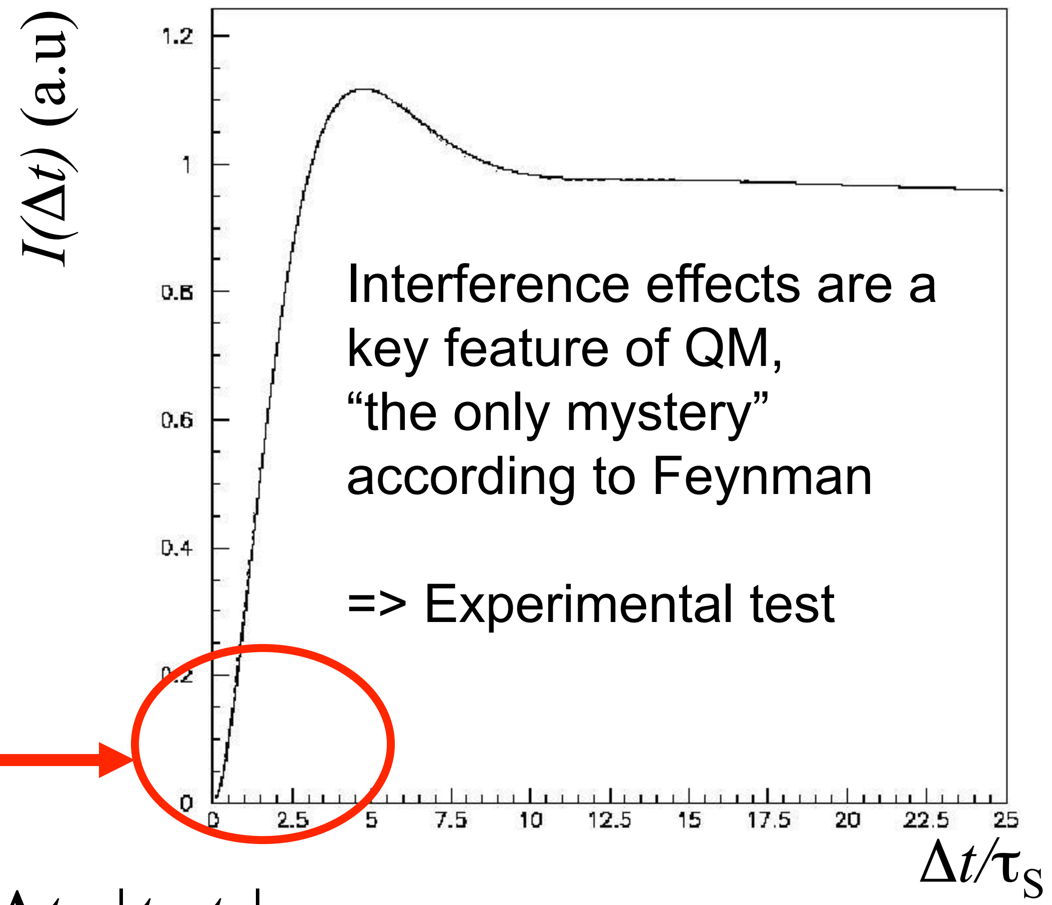

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$\phi \to K_S K_L \to \pi^+\pi^- \pi^+\pi^-$: test of quantum coherence

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

$$I(\pi^+\pi^-,\pi^+\pi^-;\Delta t) = \tfrac{N}{2}\Big[\left|\langle\pi^+\pi^-,\pi^+\pi^-|K^0\overline{K}^0(\Delta t)\rangle\right|^2 + \left|\langle\pi^+\pi^-,\pi^+\pi^-|\overline{K}^0K^0(\Delta t)\rangle\right|^2$$
$$-2\Re\left(\langle\pi^+\pi^-,\pi^+\pi^-|K^0\overline{K}^0(\Delta t)\rangle\langle\pi^+\pi^-,\pi^+\pi^-|\overline{K}^0K^0(\Delta t)\rangle^*\right)\Big]$$

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$$-(1-\zeta_{0\bar{0}})\cdot 2\Re\left(\langle \pi^+\pi^-,\pi^+\pi^- | K^0\overline{K}^0(\Delta t)\rangle \langle \pi^+\pi^-,\pi^+\pi^- | \overline{K}^0 K^0(\Delta t)\rangle^* \right) \Big]$$

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Decoherence parameter:

$\zeta_{0\bar{0}} = 0 \quad \rightarrow \quad$ QM

$\zeta_{0\bar{0}} = 1 \quad \rightarrow \quad$ total decoherence

(also known as Furry's hypothesis or spontaneous factorization) [W.Furry, PR 49 (1936) 393]

Bertlmann, Grimus, Hiesmayr PR D60 (1999) 114032

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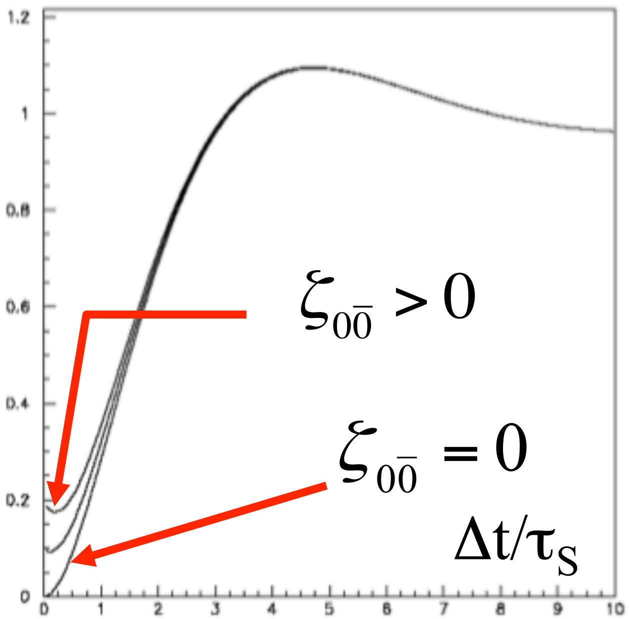

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- Analysed data: L=1.5 fb^{-1}
- Fit including Δt resolution and efficiency effects + regeneration

KLOE result: PLB 642(2006) 315
Found. Phys. 40 (2010) 852

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

Observable **suppressed by CP violation**: $|\eta_{+-}|^2 \sim |\varepsilon|^2 \sim 10^{-6}$
=> terms $\zeta_{00}/|\eta_{+-}|^2$ => **high sensitivity to ζ_{00}**

From CPLEAR data, Bertlmann et al. (PR D60 (1999) 114032) obtain:

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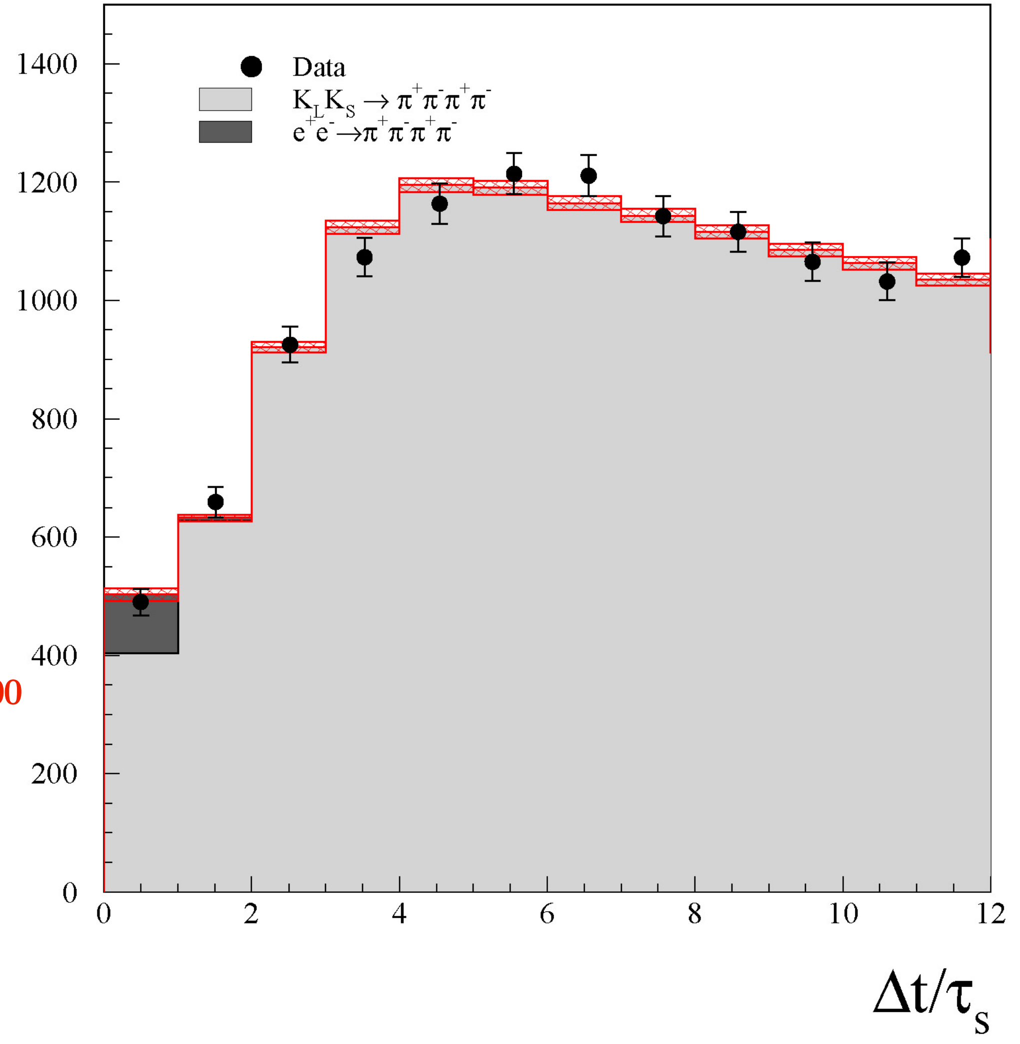
$$\zeta^{B}_{0\bar{0}} = 0.029 \pm 0.057$$



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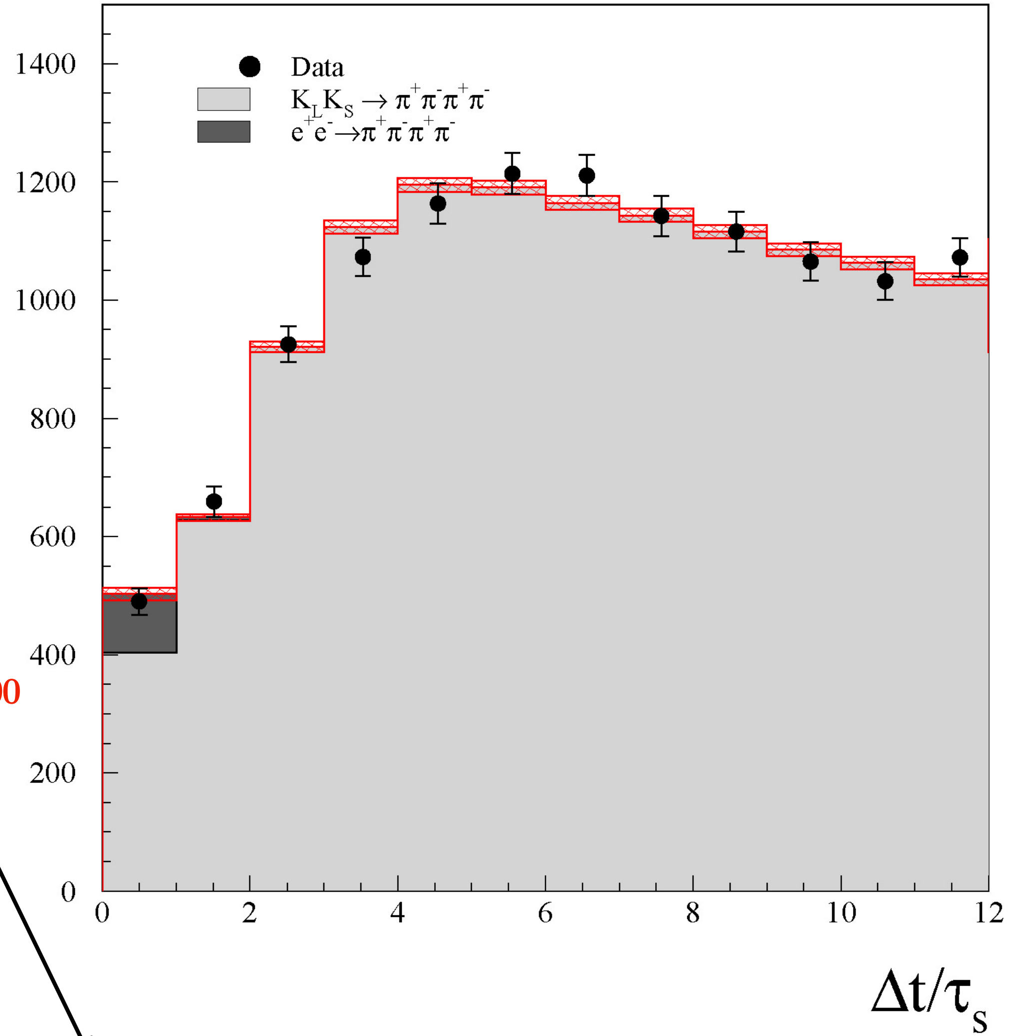

Best precision achievable in an entangled system

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Cinelli et al. PHYSICAL REVIEW A **70**, 022321 (2004)

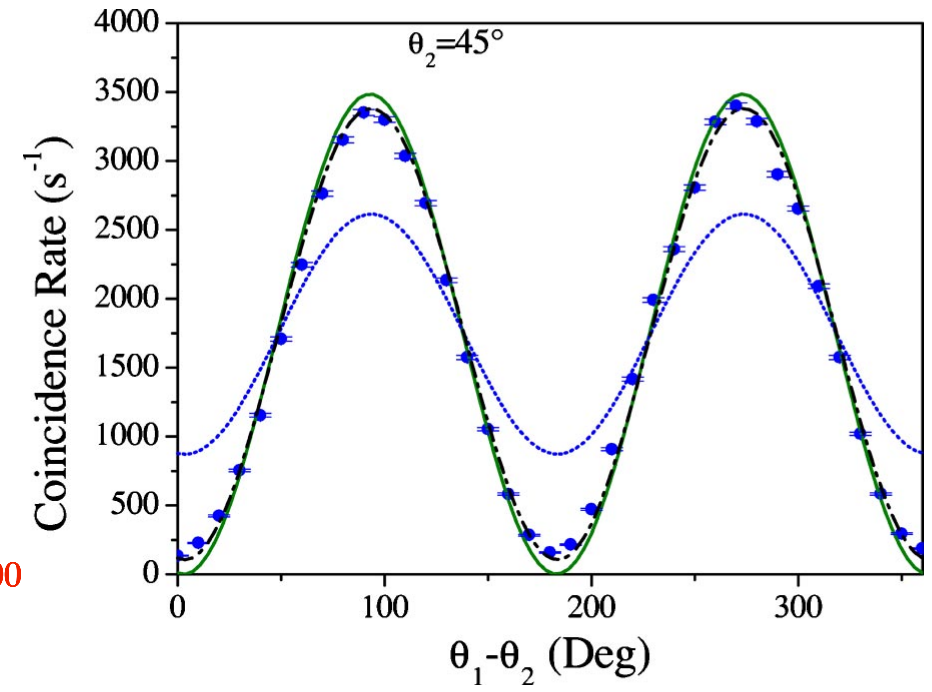


FIG. 2. Bell inequalities test. The selected state is $|\Phi^-\rangle = (1/\sqrt{2})(|H_1,H_2\rangle - |V_1,V_2\rangle)$.

$\Delta t/\tau_S$

Best precision achievable in an entangled system

Search for decoherence and CPT violation effects

Decoherence and CPT violation

S. Hawking (1975)

Possible decoherence due quantum gravity effects (BH evaporation)
(apparent loss of unitarity):
Black hole information loss paradox =>
Possible decoherence near a black hole.

("like candy rolling on the tongue" by J. Wheeler)

Hawking [1] suggested that at a microscopic level, in a quantum gravity picture, non-trivial space-time fluctuations (generically space-time foam) could give rise to decoherence effects, **which would necessarily entail a violation of CPT** [2].

Modified Liouville – von Neumann equation for the density matrix of the kaon system with 3 new CPTV parameters α,β,γ [3]:

$$\dot{\rho}(t) = \underbrace{-iH\rho + i\rho H^{+}}_{\text{QM}} + L(\rho;\alpha,\beta,\gamma)$$

extra term inducing decoherence:
pure state => mixed state

[1] Hawking, Comm.Math.Phys.87 (1982) 395; [2] Wald, PR D21 (1980) 2742;[3] Ellis et. al, NP B241 (1984) 381; Ellis, Mavromatos et al. PRD53 (1996)3846; Handbook on kaon interferometry [hep-ph/0607322],
M. Arzano PRD90 **(2014)** 024016 => Theories with Planck scale deformed symmetries can induce decoherence

Decoherence and CPT violation

S. Hawking (1975)

Possible decoherence due quantum gravity effects (BH evaporation)
(apparent loss of unitarity):
Black hole information loss paradox =>
Possible decoherence near a black hole.

("like candy rolling on the tongue" by J. Wheeler)

Hawking [1] suggested that at a microscopic level, in a quantum gravity picture, non-trivial space-time fluctuations (generically space-time foam) could give rise to decoherence effects, **which would necessarily entail a violation of CPT** [2].

Modified Liouville – von Neumann equation for the density matrix of the kaon system with 3 new CPTV parameters α,β,γ [3]:

$$\dot{\rho}(t) = \underbrace{-iH\rho + i\rho H^{+}}_{\text{QM}} + L(\rho;\alpha,\beta,\gamma)$$

at most:

$$\alpha,\beta,\gamma = O\left(\frac{M_K^2}{M_{PLANCK}}\right) \approx 2\times10^{-20}\ \text{GeV}$$

[1] Hawking, Comm.Math.Phys.87 (1982) 395; [2] Wald, PR D21 (1980) 2742;[3] Ellis et. al, NP B241 (1984) 381;
Ellis, Mavromatos et al. PRD53 (1996)3846; Handbook on kaon interferometry [hep-ph/0607322],
M. Arzano PRD90 **(2014)** 024016 => Theories with Planck scale deformed symmetries can induce decoherence

$\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^- \pi^+\pi^-$: decoherence and CPT violation

Study of time evolution of **single kaons** decaying in $\pi^+\pi^-$ and semileptonic final state

CPLEAR **PLB 364, 239 (1999)**

$$\alpha = (-0.5 \pm 2.8) \times 10^{-17} \text{ GeV}$$
$$\beta = (2.5 \pm 2.3) \times 10^{-19} \text{ GeV}$$
$$\gamma = (1.1 \pm 2.5) \times 10^{-21} \text{ GeV}$$

single kaons

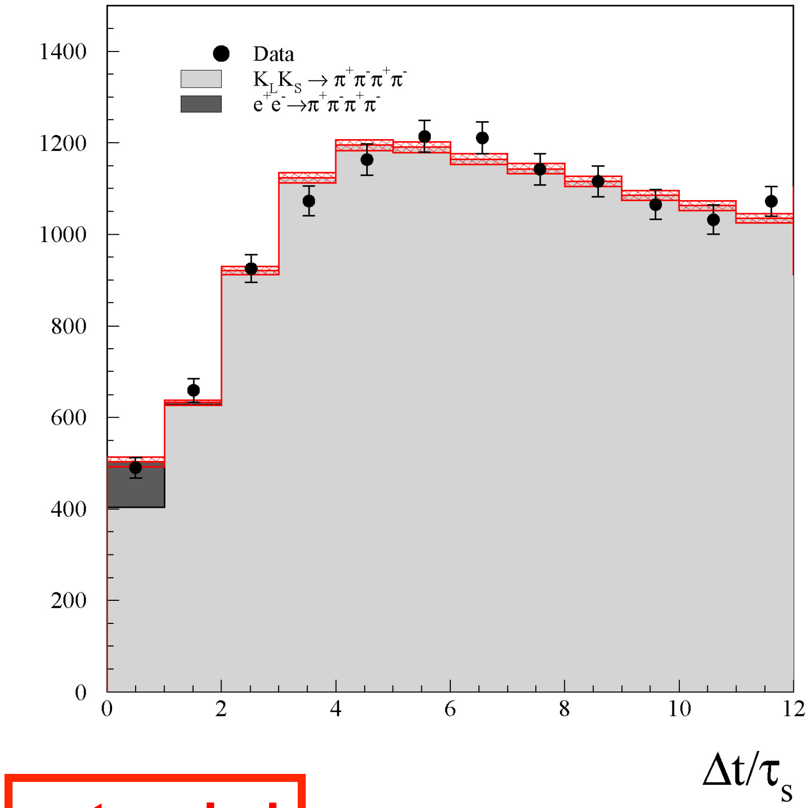
In the complete positivity hypothesis
$\alpha = \gamma$, $\beta = 0$
=> only one independent parameter: γ

The fit with $I(\pi^+\pi^-,\pi^+\pi^-;\Delta t,\gamma)$ gives:

KLOE result L=1.5 fb^{-1}

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

PLB 642(2006) 315
Found. Phys. 40 (2010) 852



entangled kaons

$\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^- \pi^+\pi^-$: CPT violation in entangled K states

In presence of decoherence and CPT violation induced by quantum gravity (CPT operator "ill-defined") the definition of the particle-antiparticle states could be modified. This in turn could induce a breakdown of the correlations imposed by Bose statistics (EPR correlations) to the kaon state:

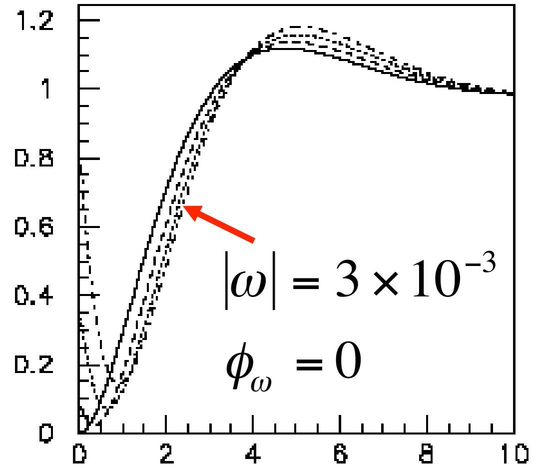
[Bernabeu, et al. PRL 92 (2004) 131601, NPB744 (2006) 180].

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

at most one expects:

$$|\omega|^2 = O\left(\frac{E^2/M_{PLANCK}}{\Delta\Gamma}\right) \approx 10^{-5} \Rightarrow |\omega| \sim 10^{-3}$$

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



$\Delta t/\tau_S$

In some microscopic models of space-time foam arising from non-critical string theory:

[Bernabeu, Mavromatos, Sarkar PRD 74 (2006) 045014]

$$|\omega| \sim 10^{-4} \div 10^{-5}$$

The maximum sensitivity to ω is expected for $f_1 = f_2 = \pi^+\pi^-$

All CPTV effects induced by QG (α,β,γ,ω) could be simultaneously disentangled.

$\phi \to K_S K_L \to \pi^+\pi^- \pi^+\pi^-$: CPT violation in entangled K states

Fit of $I(\pi^+\pi^-,\pi^+\pi^-;\Delta t,\omega)$:

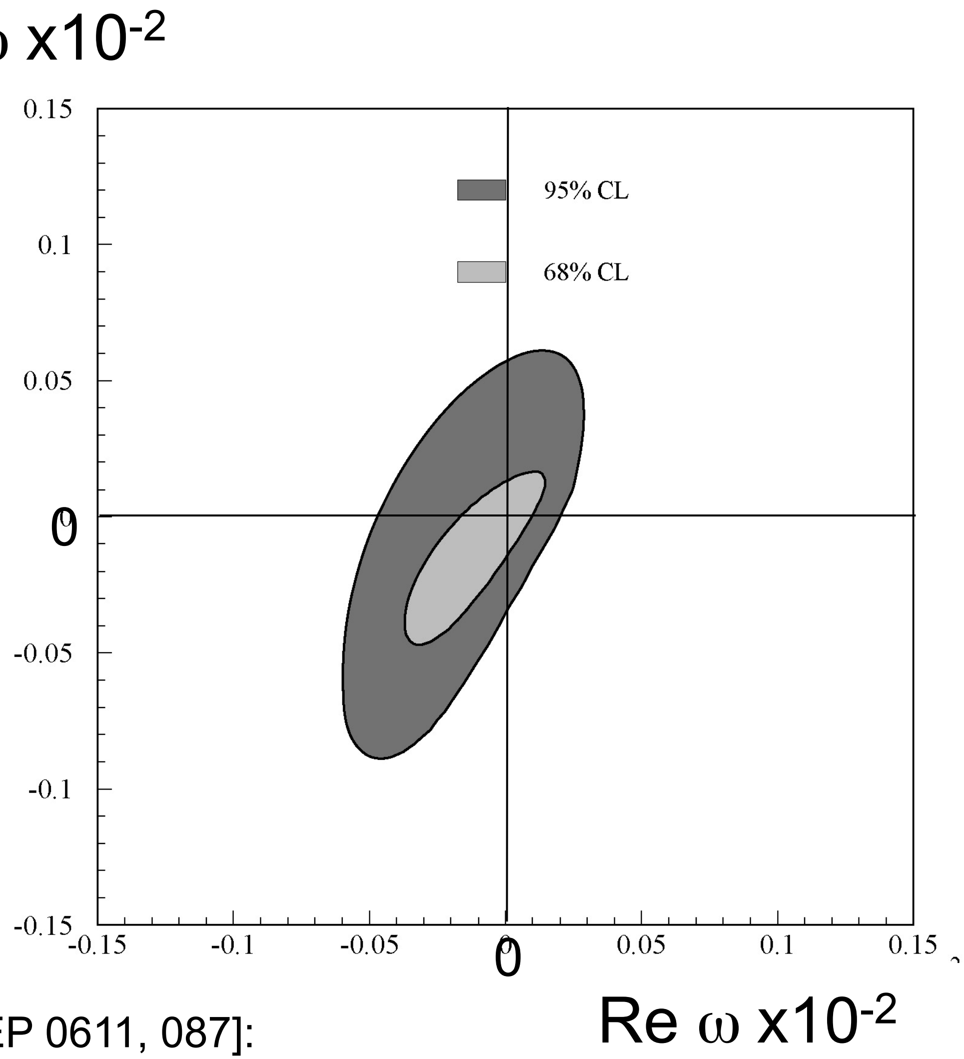
- Analysed data: 1.5 fb^{-1}

KLOE result: PLB 642(2006) 315
Found. Phys. 40 (2010) 852

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

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

$$|\omega| < 1.0\times 10^{-3} \quad \text{at } 95\% \text{ C.L.}$$



In the B system [Alvarez, Bernabeu, Nebot JHEP 0611, 087]:

$$-0.0084 \le \Re\omega \le 0.0100 \quad \text{at } 95\% \text{ C.L.}$$

CPT symmetry and Lorentz invariance test

CPT and Lorentz invariance violation (SME)

- CPT theorem :

Exact CPT invariance holds for any quantum field theory which assumes:
(1) Lorentz invariance (2) Locality (3) Unitarity (i.e. conservation of probability).

- “Anti-CPT theorem” (Greenberger 2002):

Any unitary, local, point-particle quantum field theory that violates CPT invariance necessarily violates Lorentz invariance.

- Kostelecky et al. developed a phenomenological effective model providing a framework for CPT and Lorentz violations, based on spontaneous breaking of CPT and Lorentz symmetry, which might happen in quantum gravity (e.g. in some models of string theory)

Standard Model Extension (SME) [Kostelecky PRD61, 016002, PRD64, 076001]

CPT violation in neutral kaons according to SME:

- At first order CPTV appears only in mixing parameter δ (no direct CPTV in decay)
- δ cannot be a constant (momentum dependence)

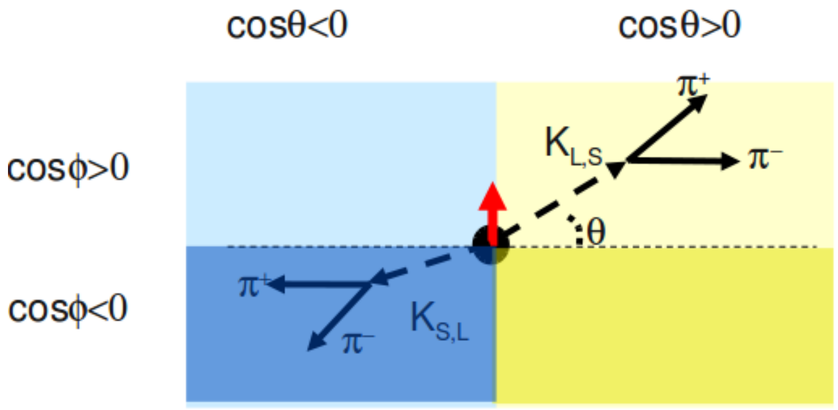
$$\varepsilon_{S,L} = \varepsilon \pm \delta \qquad \delta = i \sin\phi_{SW} e^{i\phi_{SW}} \gamma_K \left(\Delta a_0 - \vec{\beta}_K \cdot \Delta\vec{a}\right) / \Delta m$$

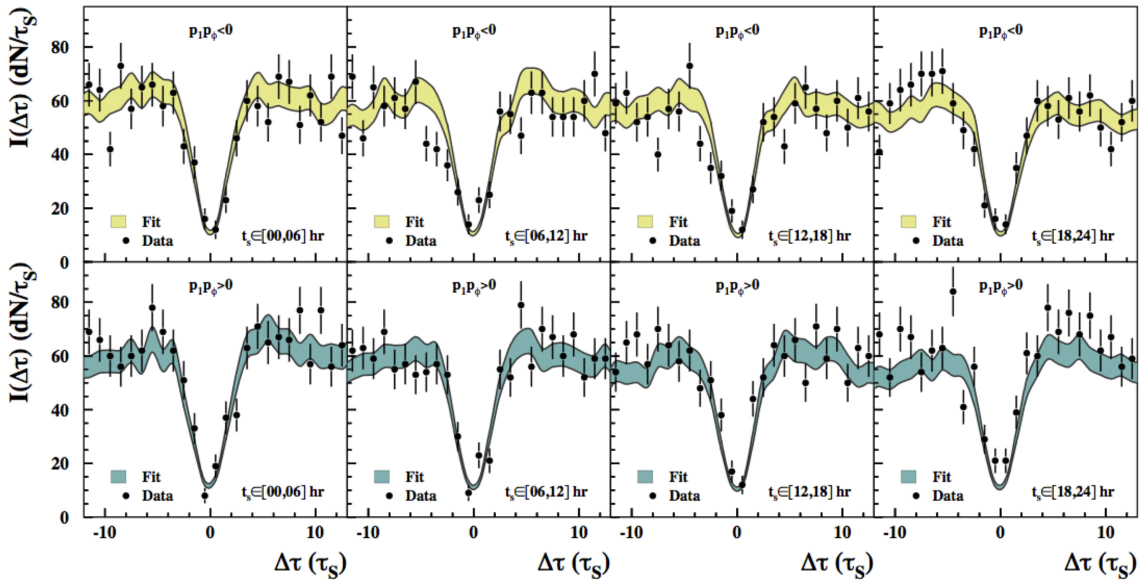
where $\Delta a_\mu = a_\mu^{q2} - a_\mu^{q1}$ are four parameters associated to SME lagrangian terms $-a_\mu \bar{q}\gamma^\mu q$ for the valence quarks and related to CPT and Lorentz violation.

Search for CPTV and LV: results

$$\delta = i \sin\phi_{SW} e^{i\phi_{SW}} \gamma_K \left(\Delta a_0 - \vec{\beta}_K \cdot \Delta\vec{a}\right) / \Delta m$$

Data divided in
4 sidereal time bins x 2 angular bins
Simultaneous fit of the Δt distributions
to extract Δa_μ parameters





KLOE **PLB 730 (2014) 89** with L=1.7 fb^{-1}

$$\Delta a_0 = \left(-6.0 \pm 7.7_{STAT} \pm 3.1_{SYST}\right) \times 10^{-18} \text{ GeV}$$

$$\Delta a_X = \left(0.9 \pm 1.5_{STAT} \pm 0.6_{SYST}\right) \times 10^{-18} \text{ GeV}$$

$$\Delta a_Y = \left(-2.0 \pm 1.5_{STAT} \pm 0.5_{SYST}\right) \times 10^{-18} \text{ GeV}$$

$$\Delta a_Z = \left(-3.1 \pm 1.7_{STAT} \pm 0.6_{SYST}\right) \times 10^{-18} \text{ GeV}$$

presently the most precise measurements in the quark sector of the SME

B meson system: $\Delta a^B_{//,X,Y} \sim O(10^{-15}$ GeV) $\Delta a^B_{perp} \sim O(10^{-13}$ GeV) [LHCb PRL116 (2016) 241601]

D meson system: $\Delta a^D_{x,y}$, $(\Delta a^D_0 - 0.6\ \Delta a^D_Z) \sim O(10^{-13}$ GeV) [Focus PLB 556 (2003) 7]

Next Future perspectives

KLOE-2 at upgraded DAΦNE

DAΦNE upgraded in luminosity:

- For the very first time the "crab-waist" concept – an interaction scheme, developed in Frascati, where the transverse dimensions of the beams and their crossing angle are tuned to maximize the machine luminosity – has been applied in presence of a high-field detector solenoid.

KLOE-2 experiment:

- extend the KLOE physics program at DAΦNE upgraded in luminosity
- Collect L>5 fb^{-1} of integrated luminosity in the next couple of years

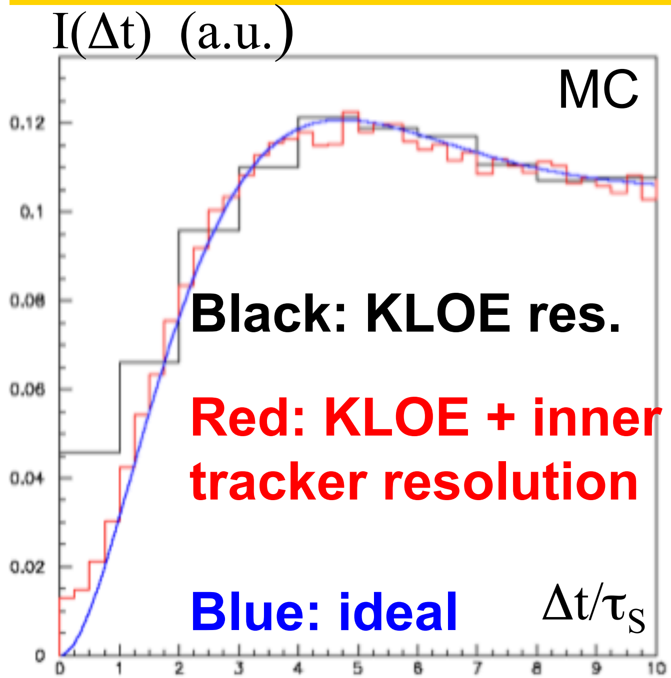
Physics program (see EPJC 68 (2010) 619-681)

- Neutral kaon interferometry, CPT symmetry & QM tests
- Kaon physics, CKM, LFV, rare K_S decays
- η,η' physics
- Light scalars, $\gamma\gamma$ physics
- Hadron cross section at low energy, a_μ
- Dark forces: search for light U boson

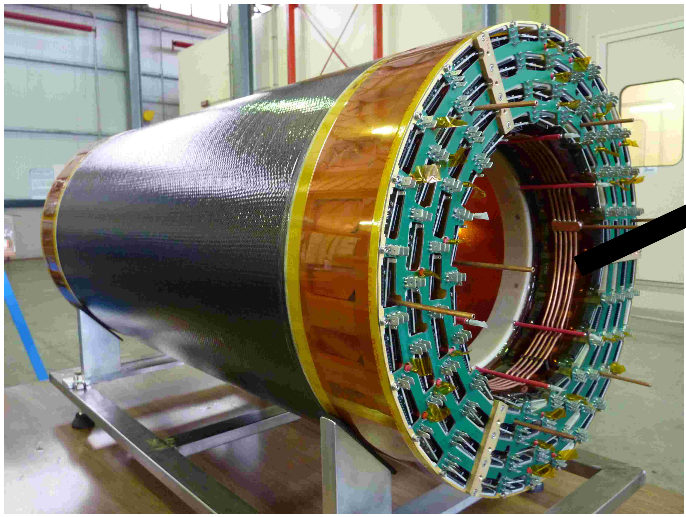
Detector upgrade:

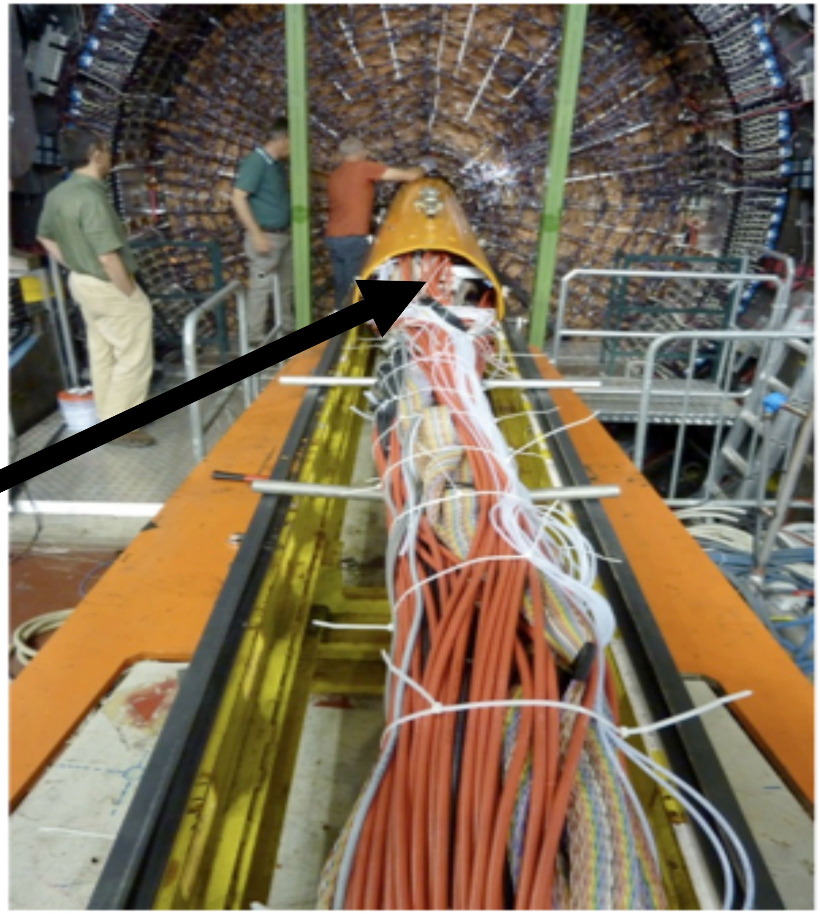
- $\gamma\gamma$ tagging system
- inner tracker
- small angle and quad calorimeters
- FEE maintenance and upgrade
- Computing and networking update
- etc.. (Trigger, software, …)

Inner tracker at KLOE-2

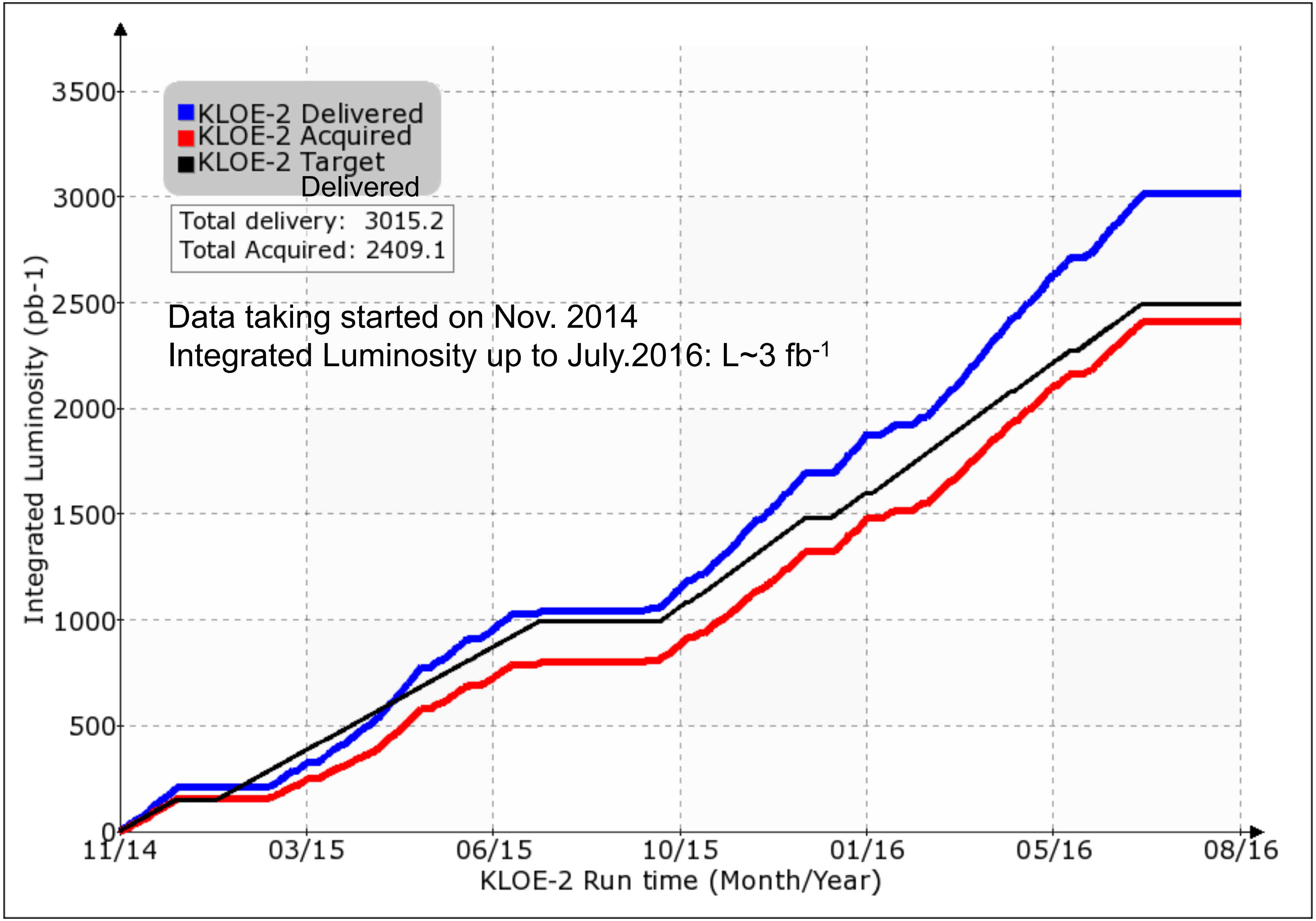


The KLOE detector has been improved with an inner tracker based on an innovative cylindrical GEM technology to improve vertex resolution close to the interaction region, and sensitivity around Δt~0.





KLOE-2 data taking in progress



Prospects for KLOE-2

Param.	Present best published measurement	KLOE-2 (IT) L=5 fb^{-1} (stat.)	KLOE-2 (IT) L=10 fb^{-1} (stat.)
A_S	$(1.5 \pm 11) \times 10^{-3}$	$\pm 2.7 \times 10^{-3}$	$\pm 1.9 \times 10^{-3}$
$\zeta_{0\bar{0}}$	$(0.1 \pm 1.0) \times 10^{-6}$	$\pm 0.26 \times 10^{-6}$	$\pm 0.18 \times 10^{-6}$
ζ_{SL}	$(0.3 \pm 1.9) \times 10^{-2}$	$\pm 0.49 \times 10^{-2}$	$\pm 0.35 \times 10^{-2}$
α	$(-0.5 \pm 2.8) \times 10^{-17}$ GeV	$\pm 5.0 \times 10^{-17}$ GeV	$\pm 3.5 \times 10^{-17}$ GeV
β	$(2.5 \pm 2.3) \times 10^{-19}$ GeV	$\pm 0.50 \times 10^{-19}$ GeV	$\pm 0.35 \times 10^{-19}$ GeV
γ	$(1.1 \pm 2.5) \times 10^{-21}$ GeV compl. pos. hyp. $(0.7 \pm 1.2) \times 10^{-21}$ GeV	$\pm 0.75 \times 10^{-21}$ GeV compl. pos. hyp. $\pm 0.33 \times 10^{-21}$ GeV	$\pm 0.53 \times 10^{-21}$ GeV compl. pos. hyp. $\pm 0.23 \times 10^{-21}$ GeV
$Re(\omega)$	$(-1.6 \pm 2.6) \times 10^{-4}$	$\pm 0.70 \times 10^{-4}$	$\pm 0.49 \times 10^{-4}$
$Im(\omega)$	$(-1.7 \pm 3.4) \times 10^{-4}$	$\pm 0.86 \times 10^{-4}$	$\pm 0.61 \times 10^{-4}$
Δa_0	$(-6.0 \pm 8.3) \times 10^{-18}$ GeV	$\pm 2.2 \times 10^{-18}$ GeV	$\pm 1.6 \times 10^{-18}$ GeV
Δa_Z	$(3.1 \pm 1.8) \times 10^{-18}$ GeV	$\pm 0.50 \times 10^{-18}$ GeV	$\pm 0.35 \times 10^{-18}$ GeV
Δa_X	$(0.9 \pm 1.6) \times 10^{-18}$ GeV	$\pm 0.44 \times 10^{-18}$ GeV	$\pm 0.31 \times 10^{-18}$ GeV
Δa_Y	$(-2.0 \pm 1.6) \times 10^{-18}$ GeV	$\pm 0.44 \times 10^{-18}$ GeV	$\pm 0.31 \times 10^{-18}$ GeV

Conclusions

- The entangled neutral kaon system at a ϕ-factory is an excellent laboratory for the study of CPT symmetry, and the basic principles of Quantum Mechanics;
- Several parameters related to possible
    - CPT violation
    - Decoherence
    - Decoherence and CPT violation
    - CPT violation and Lorentz symmetry breaking

  have been measured at KLOE, in same cases with a precision reaching the interesting **Planck's scale region** (thanks to very **peculiar amplification mechanisms** in the K system).

- All results are consistent with no CPT symmetry violation and no decoherence

- Neutral kaon interferometry, CPT symmetry and QM tests are one of the main issues of the **KLOE-2** physics program.
- The precision of several tests could be improved by about one order of magnitude, possibly revealing such kind of effects or further pushing their experimental limits.
- In addition: implementation of a newly proposed CPT test in transitions exploiting entanglement [A.D.D., J. Bernabeu, JHEP 10 (2015) 139] (not discussed here).