

Recent results on CP and CPT test at KLOE/KLOE-2

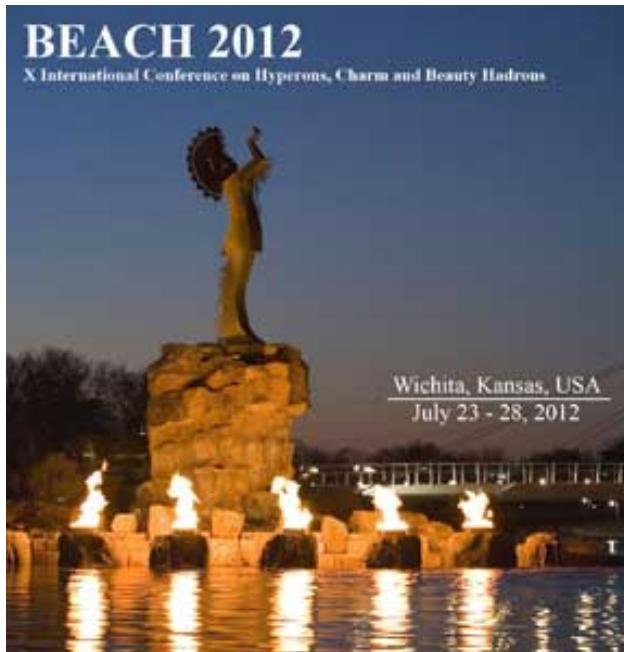


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on behalf of the KLOE-2 collaboration



Outline:

- Status of DAFNE & KLOE/KLOE-2
- CP/CPT tests with neutral K's at KLOE
- Search for CP violation in K_S decay
- CPT & Lor. test with kaon interferometry
- Perspectives and conclusions

BEACH 2012 - X International Conference on Hyperons, Charm and Beauty Hadrons
July 23rd - 28th, 2012 - Wichita, Kansas - USA

Status of DAΦNE and KLOE/KLOE-2

DAΦNE: the Frascati ϕ -factory



- e^+e^- collider @ $\sqrt{s} = M_\phi = 1019.4$ MeV
- LAB momentum $p_\phi \sim 13$ MeV/c
- $\sigma_{\text{peak}} \sim 3 \mu\text{b}$
- Separate e^+e^- rings to reduce beam-beam interaction
- Beams crossing angle: 12.5 mrad

KLOE run (2001-2005):

Daily performance: $\int L dt$ 7-8 pb⁻¹

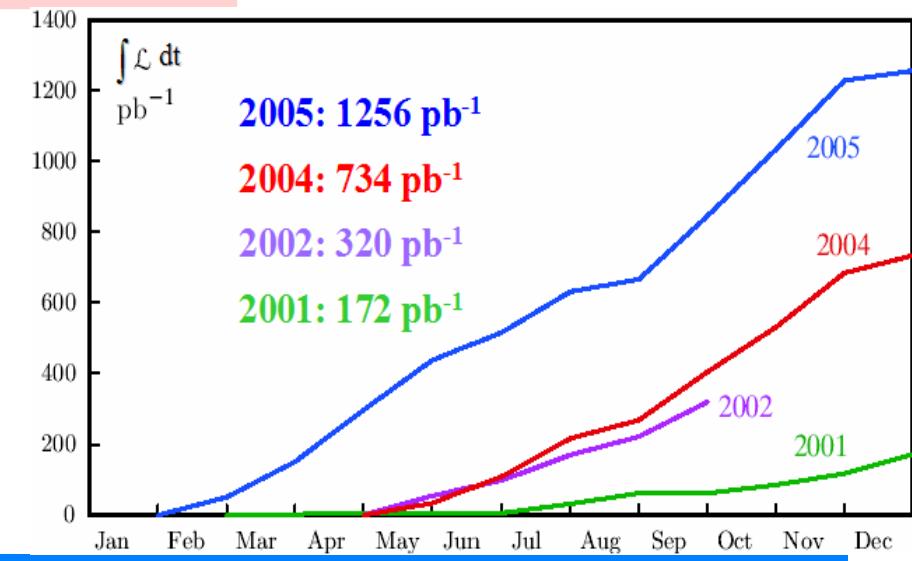
Peak $L \sim 1.5 \cdot 10^{32}$ cm⁻²s⁻¹

Total KLOE $\int L dt \sim 2.4$ fb⁻¹ at ϕ mass peak + 250 pb⁻¹ off peak (@ 1 GeV)

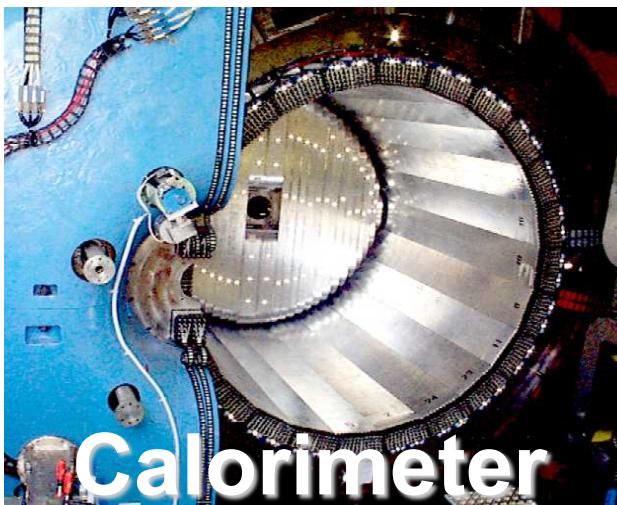
BR's for Φ decays

K^+K^-	49.1%
$K_S K_L$	34.1%
$\rho\pi + \pi^+\pi^-\pi^0$	15.5%
$\eta\gamma$	1.31%

→ $\sim 2.5 \times 10^9$ $K_S K_L$ pairs
→ $\sim 3.6 \times 10^9$ K^+K^- pairs
→ $\sim 10^8$ η 's



The KLOE detector at DAΦNE



Calorimeter

Lead/scintillating fiber

4880 PMTs

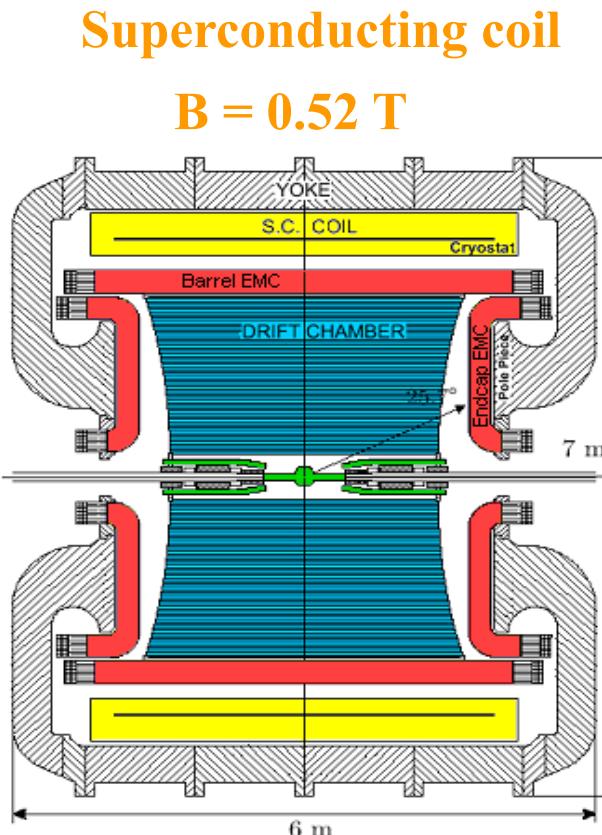
98% coverage of solid angle

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

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

(relative time between clusters)

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



Drift chamber

4 m diameter \times 3.3 m length

90% helium, 10% isobutane

12582/52140 sense/total wires

All-sereo geometry

$$\sigma_p/p \approx 0.4 \% \text{ (tracks with } \theta > 45^\circ)$$

$$\sigma_x^{\text{hit}} \approx 150 \mu\text{m (xy), 2 mm (z)}$$

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

KLOE-2 at upgraded DAΦNE

DAΦNE upgraded in luminosity:

- new scheme of the interaction region (crabbed waist scheme) at DAΦNE (proposal by P. Raimondi)
- increase L by a factor $\times 3$ demonstrated by a successful experimental test

KLOE-2 experiment:

- extend the KLOE physics program at DAΦNE upgraded in luminosity
- Collect $O(10) \text{ fb}^{-1}$ of integrated luminosity in the next 2-3 years

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

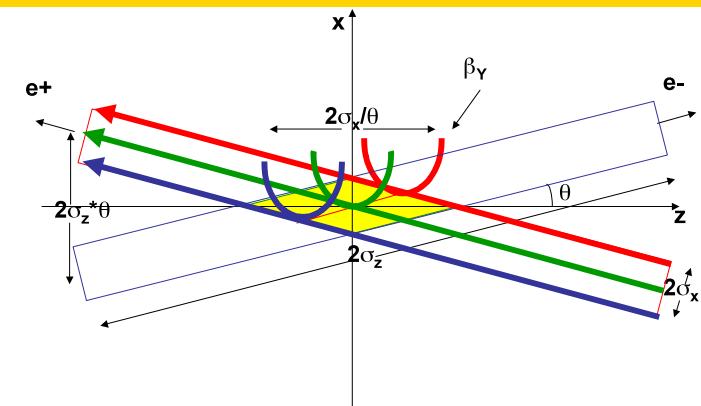
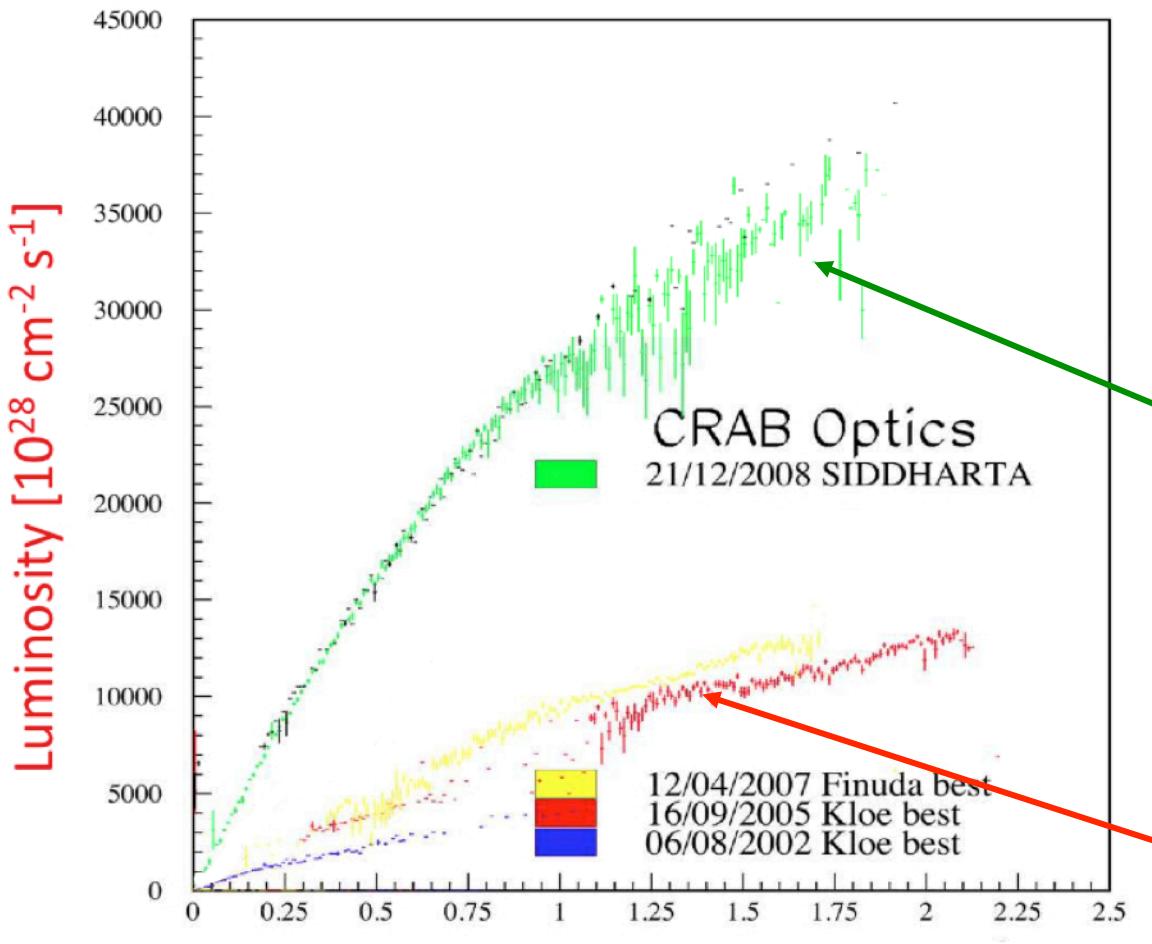
- Neutral kaon interferometry, CPT symmetry & QM tests
- Kaon physics, CKM, LFV, rare K_S decays
- η, η' physics
- Light scalars, $\gamma\gamma$ physics
- Hadron cross section at low energy, a_μ
- Dark forces: search for light U boson

Detector upgrade:

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

DAΦNE luminosity upgrade

Crabbed waist scheme at DAΦNE



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

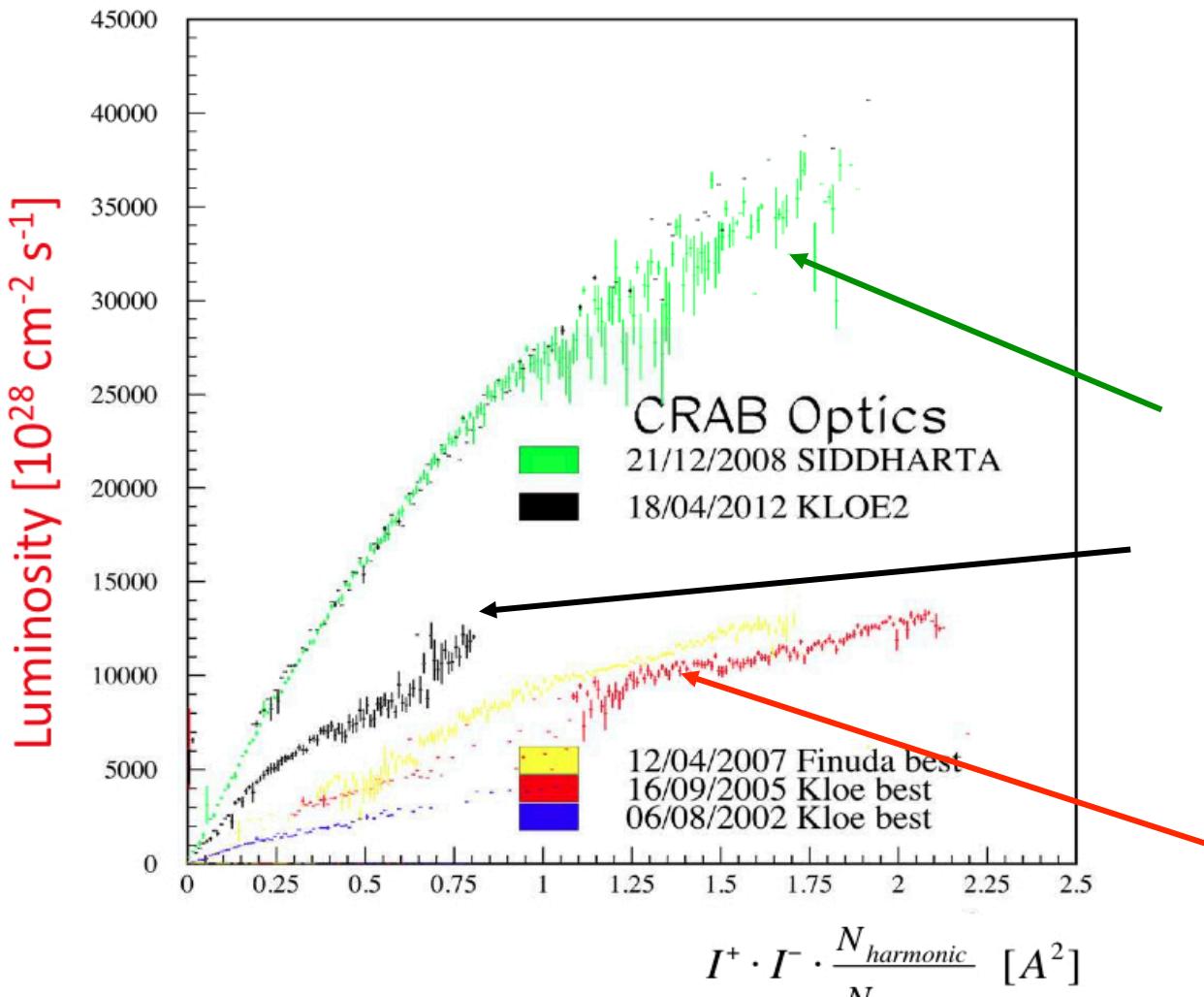
NEW COLLISION SCHEME:
Large Piwinski angle
Crab-Waist compensation SXTs

Old collision scheme

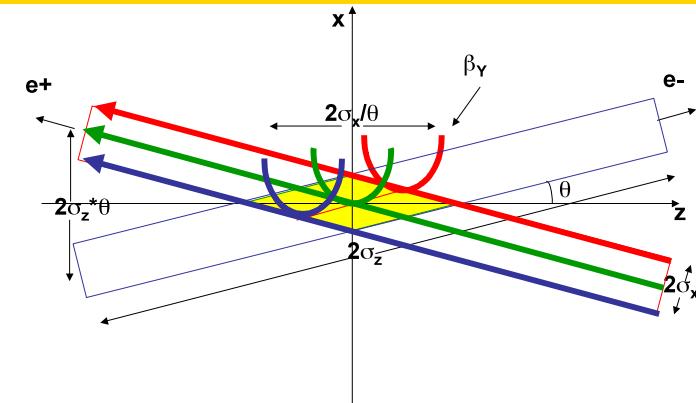
$$\text{max. expected at KLOE-2 : } L_{\text{int}} \sim 20 \text{ pb}^{-1}/\text{day} \times 200 \text{ dd/year} = 4 \text{ fb}^{-1} /\text{year}$$

DAΦNE luminosity upgrade

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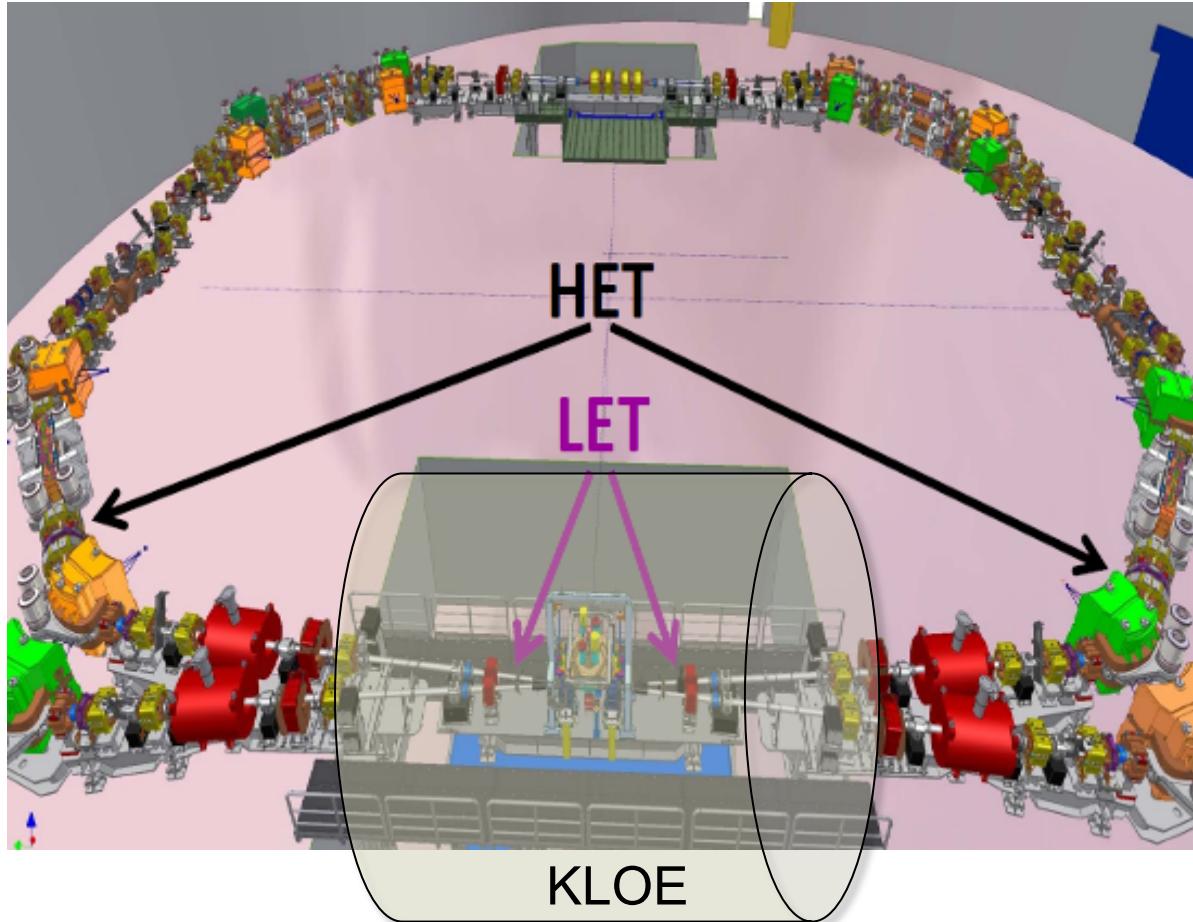
NEW COLLISION SCHEME:
Large Piwinski angle
Crab-Waist compensation SXTs

Present commissioning phase
New coll. scheme + KLOE det.

Old collision scheme

From KLOE to KLOE-2: $\gamma\gamma$ taggers

Measurement of leptons momenta in $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-X$



LET: $E_e \sim 160-230$ MeV

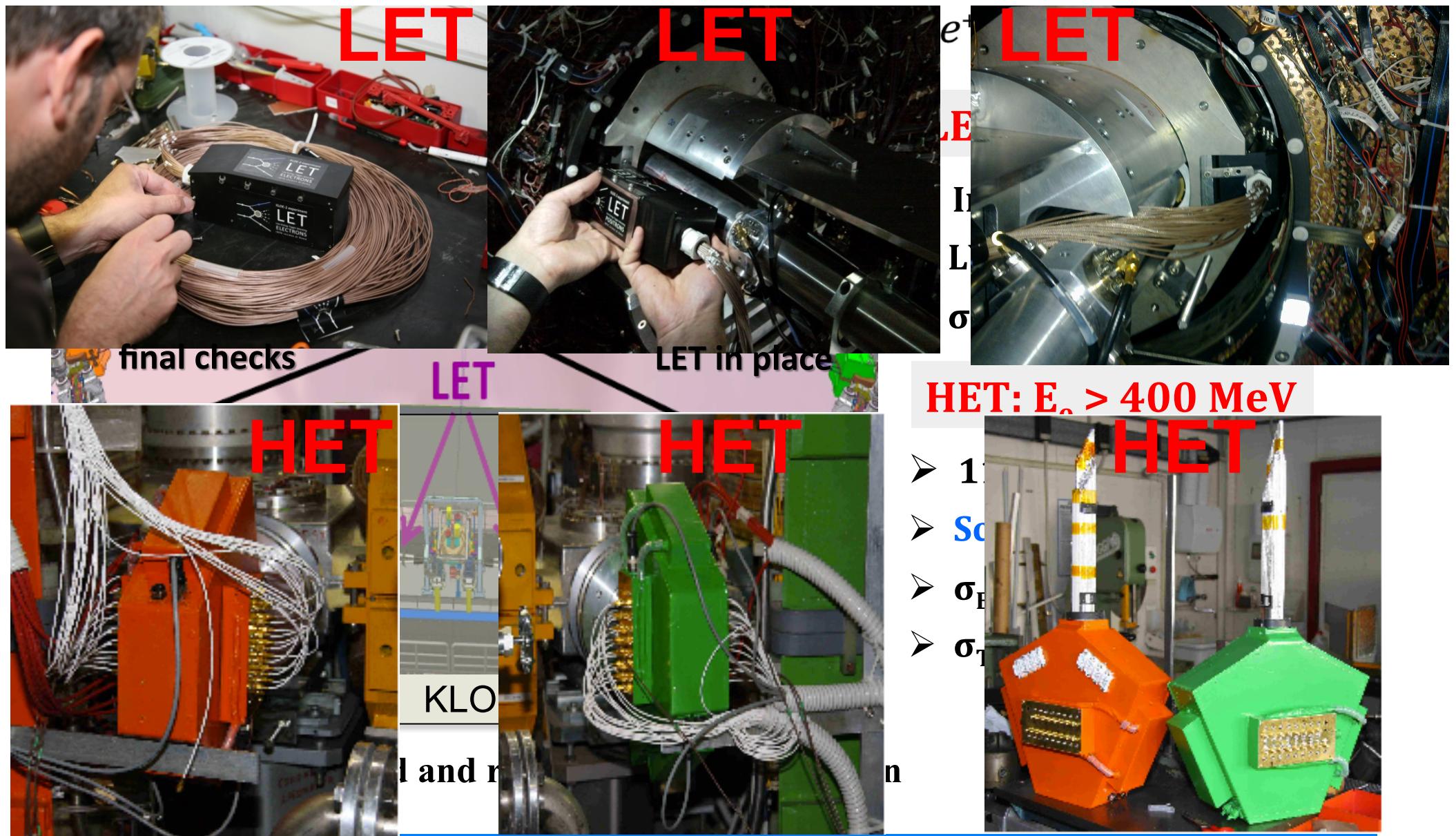
- Inside KLOE detector
- LYSO+SiPM
- $\sigma_E < 10\%$ for $E > 150$ MeV

HET: $E_e > 400$ MeV

- 11 m from IP
- Scintillator hodoscopes
- $\sigma_E \sim 2.5$ MeV
- $\sigma_T \sim 200$ ps

$\gamma\gamma$ taggers are installed and ready for the KLOE-2 run

From KLOE to KLOE-2: $\gamma\gamma$ taggers

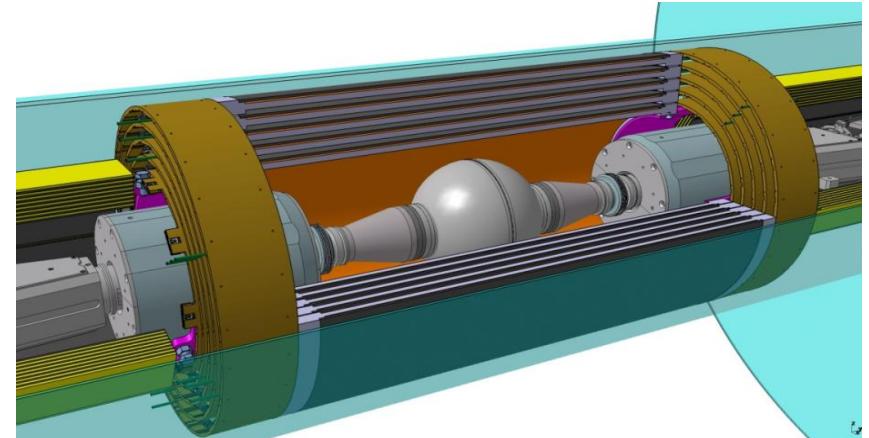


From KLOE to KLOE-2: IP detectors

Major detector upgrades ready in fall 2012, start install. end 2012:

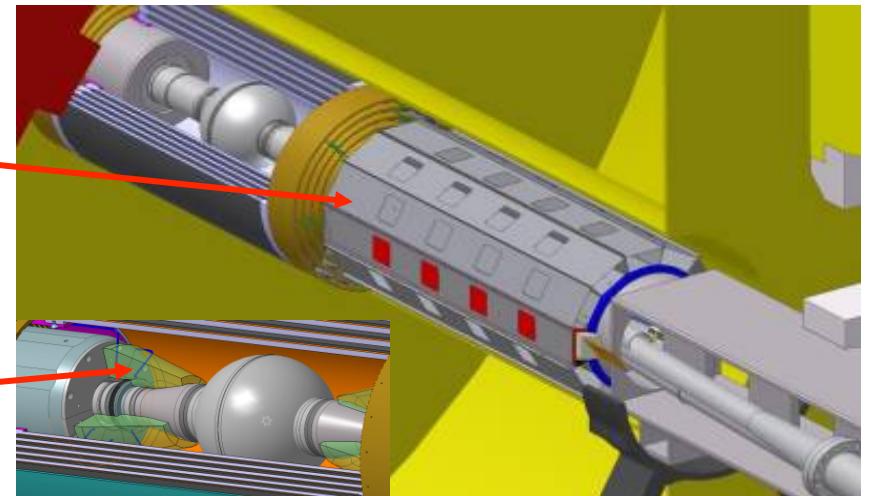
INNER TRACKER

- 4 layers of cylindrical triple GEM
- Better vertex reconstruction near IP
- Larger acceptance for low p_t tracks



QCALT

- W + scintillator tiles + SiPM/WLS
- Low-beta quadrupoles: coverage for K_L decays



CCALT

- LYSO + SiPM
- Increase acceptance for γ 's from IP ($21^\circ \rightarrow 10^\circ$)

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CP/CPT tests with neutral kaons at KLOE

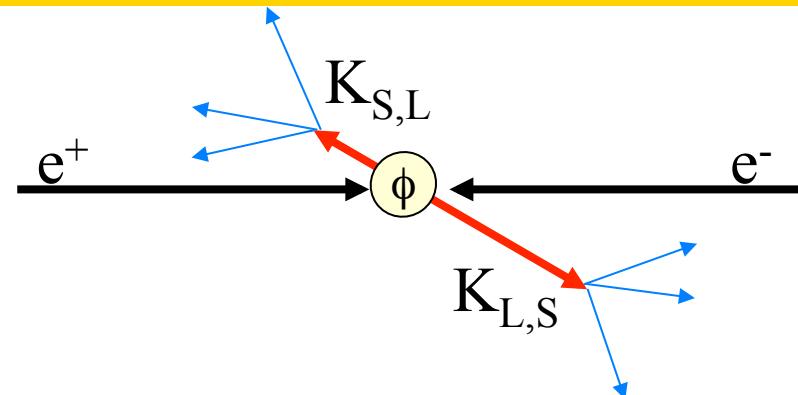
Neutral kaons at a ϕ -factory

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

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

$$p_K = 110 \text{ MeV/c}$$

$$\lambda_S = 6 \text{ mm} \quad \lambda_L = 3.5 \text{ m}$$



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

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

The detection of a kaon at large (small) times tags a K_S (K_L)
⇒ possibility to select a pure K_S beam (unique at a ϕ -factory, not possible at fixed target experiments)

List of KLOE CP/CPT tests with neutral kaons

Mode	Test of	Param.	KLOE measurement
$K_L \rightarrow \pi^+ \pi^-$	CP	BR	$(1.963 \pm 0.012 \pm 0.017) \times 10^{-3}$
$K_S \rightarrow 3\pi^0$	CP	BR	$< 1.2 \times 10^{-7}$
$K_S \rightarrow \pi e \nu$	CP	A_S	$(1.5 \pm 11) \times 10^{-3}$
$K_S \rightarrow \pi e \nu$	CPT	$\text{Re}(x)$	$(-0.8 \pm 2.5) \times 10^{-3}$
$K_S \rightarrow \pi e \nu$	CPT	$\text{Re}(y)$	$(0.4 \pm 2.5) \times 10^{-3}$
All $K_{S,L}$ BRs, η 's etc... (unitarity)	CP CPT	$\text{Re}(\varepsilon)$ $\text{Im}(\delta)$	$(159.6 \pm 1.3) \times 10^{-5}$ $(0.4 \pm 2.1) \times 10^{-5}$
$K_S K_L \rightarrow \pi^+ \pi^-, \pi^+ \pi^-$	CPT & QM	α	$(-10 \pm 37) \times 10^{-17} \text{ GeV}$
$K_S K_L \rightarrow \pi^+ \pi^-, \pi^+ \pi^-$	CPT & QM	β	$(1.8 \pm 3.6) \times 10^{-19} \text{ GeV}$
$K_S K_L \rightarrow \pi^+ \pi^-, \pi^+ \pi^-$	CPT & QM	γ	$(0.4 \pm 4.6) \times 10^{-21} \text{ GeV}$ compl. pos. hyp. $(0.7 \pm 1.2) \times 10^{-21} \text{ GeV}$
$K_S K_L \rightarrow \pi^+ \pi^-, \pi^+ \pi^-$	CPT & QM	$\text{Re}(\omega)$	$(-1.6 \pm 2.6) \times 10^{-4}$
$K_S K_L \rightarrow \pi^+ \pi^-, \pi^+ \pi^-$	CPT & QM	$\text{Im}(\omega)$	$(-1.7 \pm 3.4) \times 10^{-4}$
$K_S K_L \rightarrow \pi^+ \pi^-, \pi^+ \pi^-$	CPT & Lorentz	Δa_0	$(0.4 \pm 1.8) \times 10^{-17} \text{ GeV}$
$K_S K_L \rightarrow \pi^+ \pi^-, \pi^+ \pi^-$	CPT & Lorentz	Δa_Z	$(2.4 \pm 9.7) \times 10^{-18} \text{ GeV}$
$K_S K_L \rightarrow \pi^+ \pi^-, \pi^+ \pi^-$	CPT & Lorentz	Δa_X	$(-6.3 \pm 6.0) \times 10^{-18} \text{ GeV}$
$K_S K_L \rightarrow \pi^+ \pi^-, \pi^+ \pi^-$	CPT & Lorentz	Δa_Y	$(2.8 \pm 5.9) \times 10^{-18} \text{ GeV}$

Search for CP violation in K_S decay

$K_S \rightarrow \pi^0 \pi^0 \pi^0$: a pure CP violating decay

$$|\Psi\rangle = a(t)|K^0\rangle + b(t)|\bar{K}^0\rangle \quad i\frac{\partial}{\partial t}|\Psi\rangle = \mathbf{H}|\Psi\rangle$$

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

$$|K_S\rangle = \frac{1}{\sqrt{(1+|\varepsilon_S|)}} [|K_1\rangle + \varepsilon_S |K_2\rangle]$$

$\varepsilon_S = \varepsilon + \delta$

$$|K_L\rangle = \frac{1}{\sqrt{(1+|\varepsilon_L|)}} [|K_2\rangle + \varepsilon_L |K_1\rangle]$$

$\varepsilon_L = \varepsilon - \delta$

$3\pi^0$ is a pure $CP=-1$ state; observation of $K_S \rightarrow 3\pi^0$ is an unambiguous sign of CP violation in mixing and/or in decay. (δ: CPT viol.)

$$\eta_{000} = \frac{\langle \pi^0 \pi^0 \pi^0 | T | K_S \rangle}{\langle \pi^0 \pi^0 \pi^0 | T | K_L \rangle} = \varepsilon + \varepsilon'_{000}$$

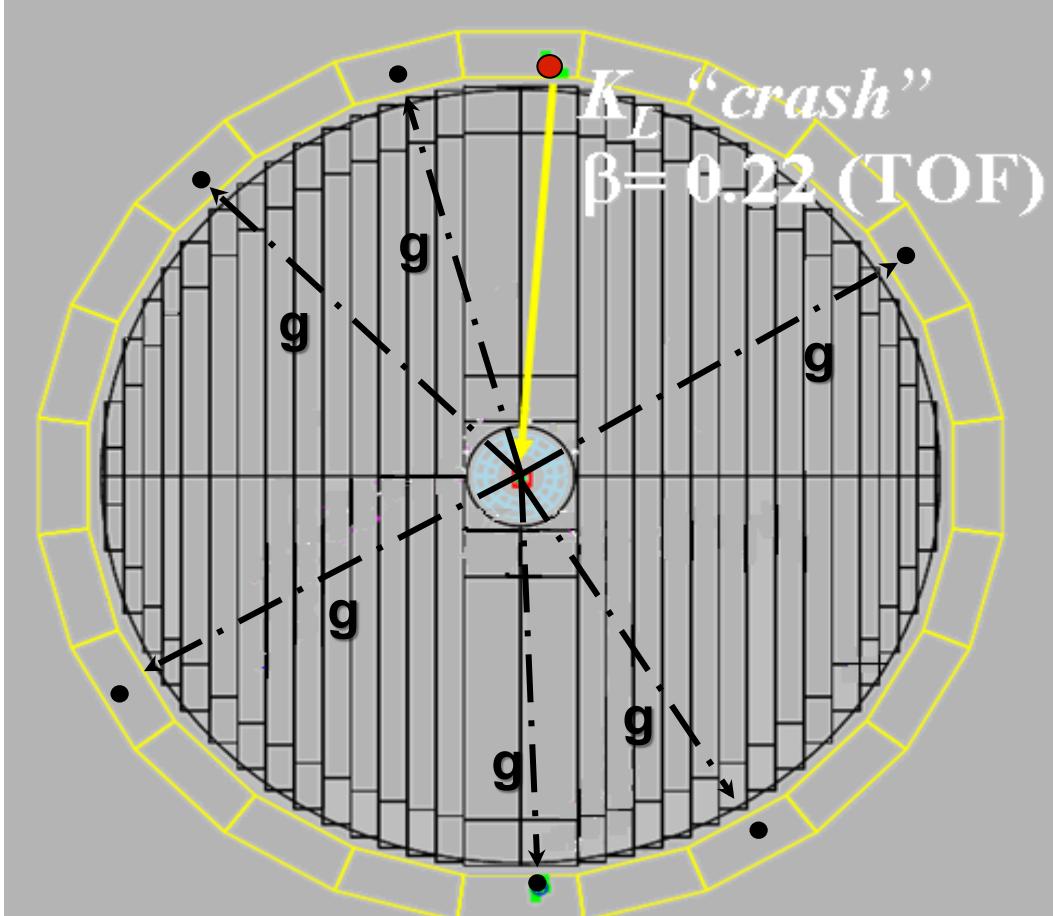
to lowest order in χ PT [PRD21,178 (1980)]:
 $\varepsilon'_{000} = -2\varepsilon'$

$$|\eta_{000}| = \sqrt{\frac{\tau_L}{\tau_S} \frac{BR(K_S \rightarrow 3\pi^0)}{BR(K_L \rightarrow 3\pi^0)}}$$

Standard Model prediction:
 $BR(K_S \rightarrow 3\pi^0) = 1.9 \cdot 10^{-9}$

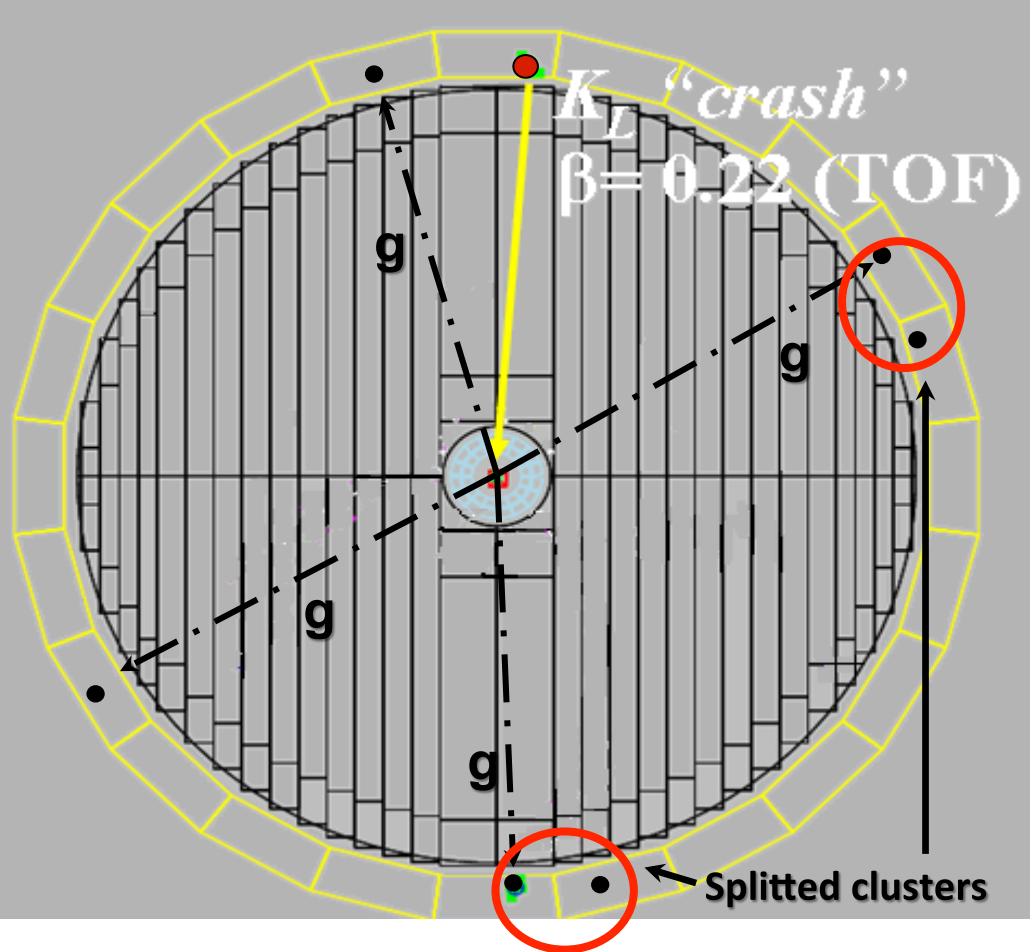
$K_S \rightarrow \pi^0\pi^0\pi^0$: search for a CP violating decay

SIGNAL



$$K_S \rightarrow 3\pi^0 \rightarrow 6\gamma$$

BACKGROUND



$$K_S \rightarrow 2\pi^0 + \text{accidental/splitted clusters}$$
$$K_L \rightarrow 3\pi, K_S \rightarrow \pi^+ \pi^- (\text{"fake } K_L \text{-crash"})$$

$K_S \rightarrow \pi^0\pi^0\pi^0$: search for a CP violating decay

SND (direct search) 1999:

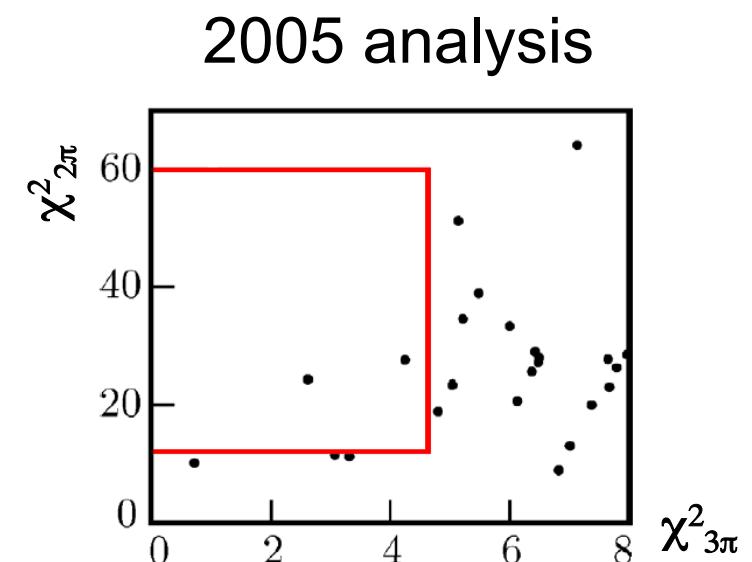
$$\text{BR}(K_S \rightarrow 3\pi^0) < 1.4 \cdot 10^{-5}$$

NA48 (interference measurement) 2004: $\text{BR}(K_S \rightarrow 3\pi^0) < 7.4 \cdot 10^{-7}$

Standard Model prediction: $\text{BR}(K_S \rightarrow 3\pi^0) = 1.9 \cdot 10^{-9}$

- K_L interactions in the calorimeter to tag K_S decay
- 6 prompt γ 's required
- Analysis based on γ counting and kinematic fit in the $2\pi^0$ and $3\pi^0$ hypothesis
- Dominant background from $K_S \rightarrow 2\pi^0 + 2$ split or 2 accidental clusters
- After all analysis cuts ($\varepsilon_{3\pi} = 24.4\%$)
 - 2 candidate events found
 - $3.13 \pm 0.82 \text{stat} \pm 0.37 \text{syst}$ expected background

KLOE [PLB619(2005)61] with $450 \text{ pb}^{-1} \Rightarrow$

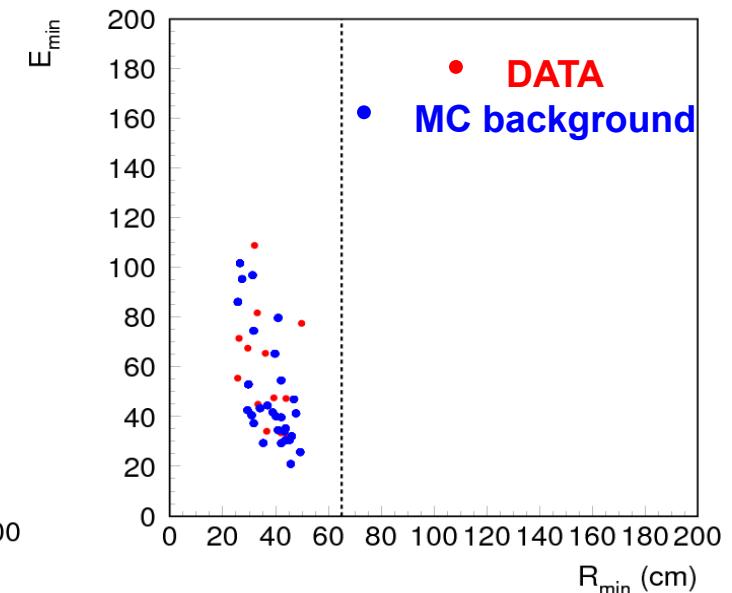
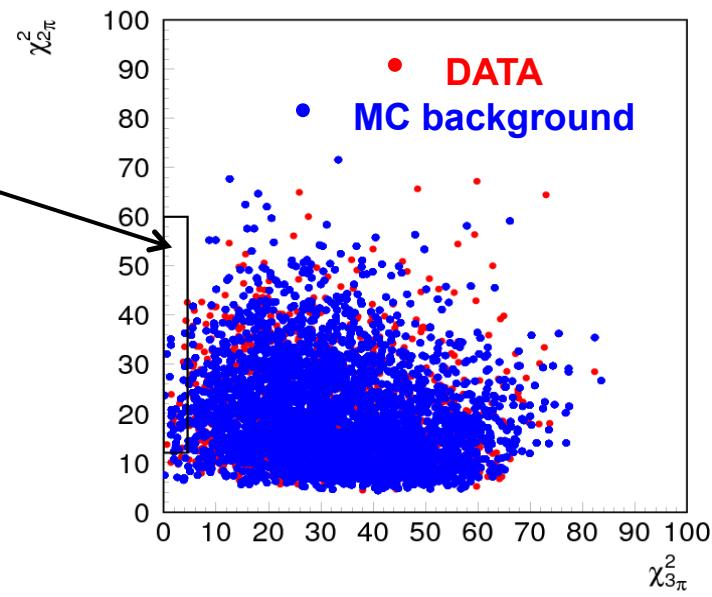


$\text{BR}(K_S \rightarrow 3\pi^0) < 1.2 \times 10^{-7}$ @ 90% CL

$|\eta_{000}| < 0.018$ @ 90% CL

$K_S \rightarrow \pi^0\pi^0\pi^0$: search for a CP violating decay

- The analysis has been updated
 - improving clustering procedure to reduce split clusters
 - hardening the $\beta^*(K_L)$ cut for tagging the K_S decays
 - processing the entire data set ($\sim 8 \times 10^7$ tagged $K_S K_L$ pairs)
- signal box
- $R_{min} > 65$ cm
- $\varepsilon_{3\pi} = 0.23(1)$
- $N_{3\pi^0} \leq 2.33/\varepsilon_{3\pi^0}$
at 90% C.L.
- Normalized to
 $N_{2\pi^0}/\varepsilon_{2\pi^0} = (1.14130 \pm 0.00011) \times 10^8$



KLOE internal refereeing completed
formal approval by KLOE collaboration ongoing
KLOE paper in preparation

$BR(K_S \rightarrow 3\pi^0) < 2.7 \times 10^{-8}$ @ 90% CL

$|\eta_{000}| < 0.009$ @ 90% CL

This result points to the feasibility of the first observation at KLOE-2

CPT and Lorentz invariance test with neutral kaon interferometry

CPT and Lorentz invariance violation (SME)

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:

- CPTV only in mixing, not in decay, at first order (i.e. $B_I = y = x_- = 0$)
- δ cannot be a constant (momentum dependence)

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

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

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

CPT and Lorentz invariance violation (SME)

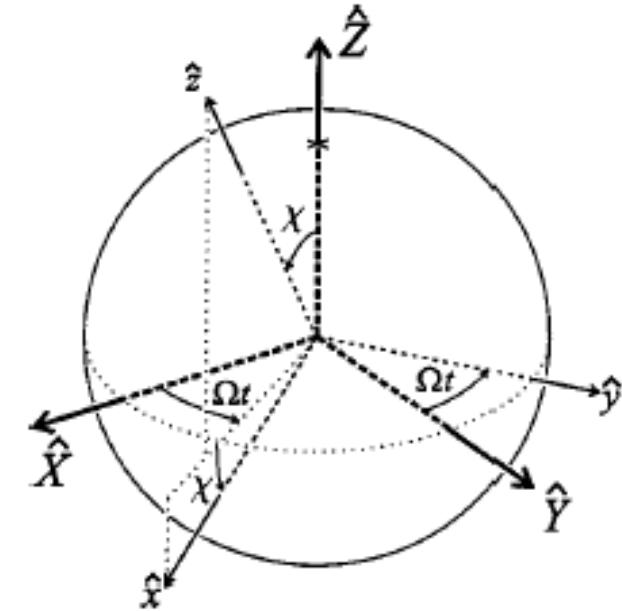
$$\delta = i \sin \phi_{SW} e^{i\phi_{SW}} \gamma_K (\Delta a_0 - \vec{\beta}_K \cdot \Delta \vec{a}) / \Delta m$$

δ depends on sidereal time t since laboratory frame rotates with Earth.

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:

$$\begin{aligned} \delta(\vec{p}, t) = & \frac{i \sin \phi_{SW} e^{i\phi_{SW}}}{\Delta m} \gamma_K \left\{ \underline{\Delta a_0} \right. \\ & + \underline{\beta_K \Delta a_Z} (\cos \theta \cos \chi - \sin \theta \sin \phi \sin \chi) \\ & + \underline{\beta_K [-\Delta a_X \sin \theta \sin \phi + \Delta a_Y (\cos \theta \sin \chi + \sin \theta \cos \phi \cos \chi)]} \sin \Omega t \\ & \left. + \underline{\beta_K [+ \Delta a_Y \sin \theta \sin \phi + \Delta a_X (\cos \theta \sin \chi + \sin \theta \cos \phi \cos \chi)]} \cos \Omega t \right\} \end{aligned}$$

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



(in general z lab. axis is non-normal to Earth's surface)

CPT and Lorentz invariance violation (SME)

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

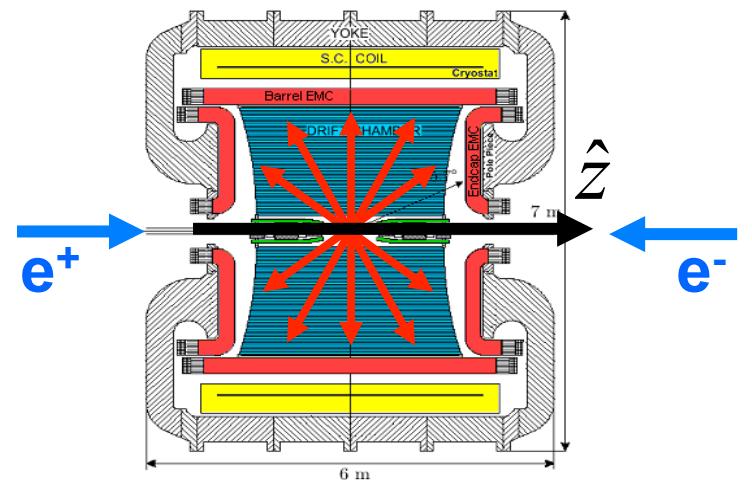
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At DAΦNE K mesons are produced with angular distribution $dN/d\Omega \propto \sin^2 \theta$

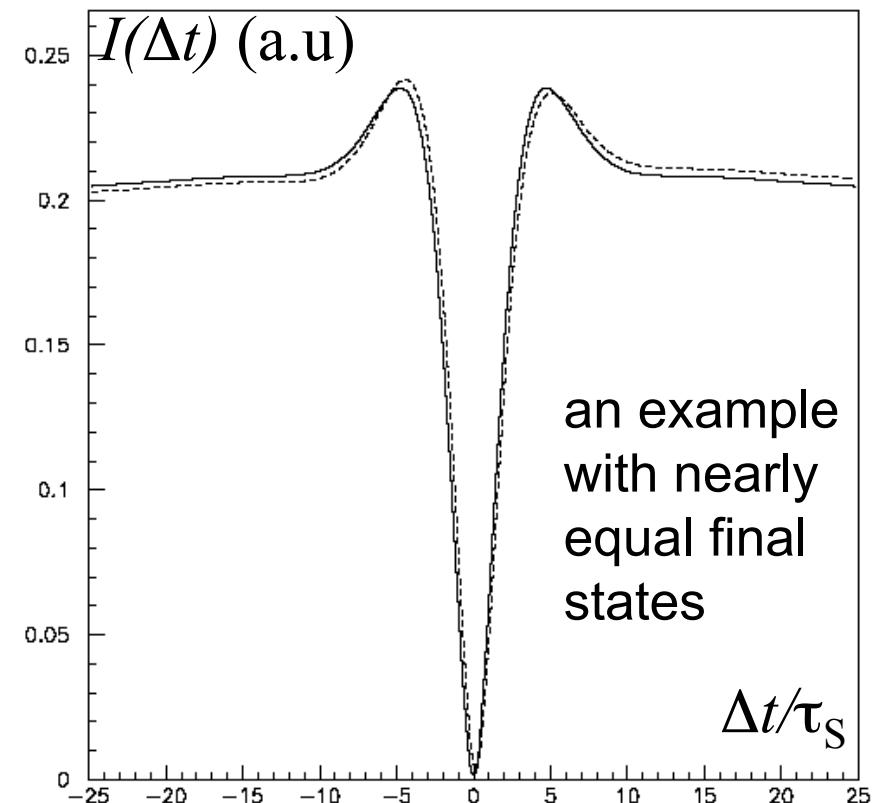
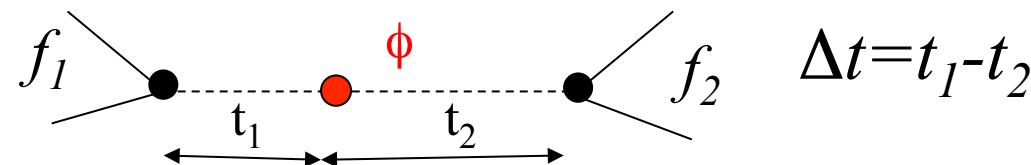


Exploiting neutral kaon interferometry

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

$$\eta_i = |\eta_i| e^{i\phi_i} = \langle f_i | T | K_L \rangle / \langle f_i | T | K_S \rangle$$

$$I(f_1, f_2; \Delta t) \propto \left\{ |\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} - 2|\eta_1||\eta_2| e^{-(\Gamma_S + \Gamma_L)\Delta t/2} \cos(\Delta m \Delta t + \phi_2 - \phi_1) \right\}$$

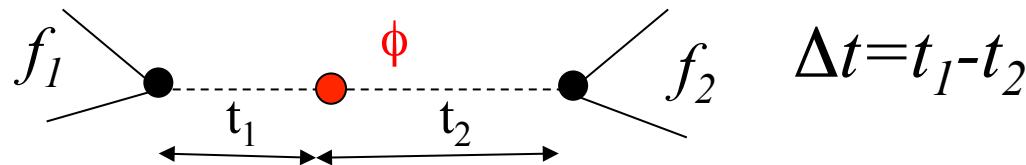


Exploiting neutral kaon interferometry

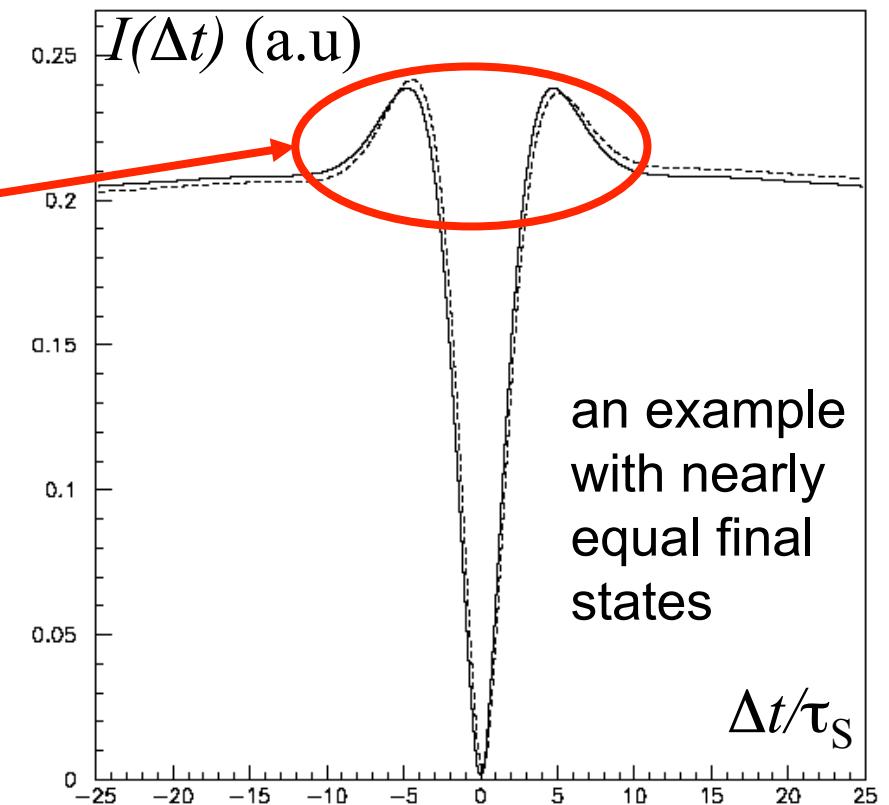
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η_2/η_1
from the asymmetry at small Δt

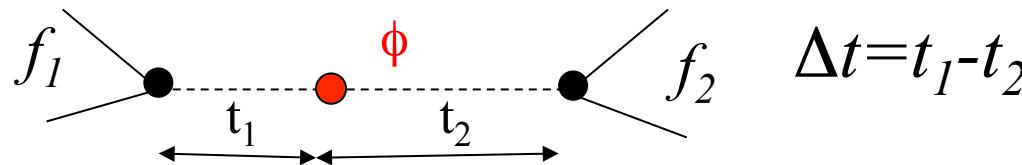


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$$|i\rangle = \frac{1}{\sqrt{2}} \left[|K^0\rangle |\bar{K}^0\rangle - |\bar{K}^0\rangle |K^0\rangle \right]$$

$$\eta_i = |\eta_i| e^{i\phi_i} = \langle f_i | T | K_L \rangle / \langle f_i | T | K_S \rangle$$

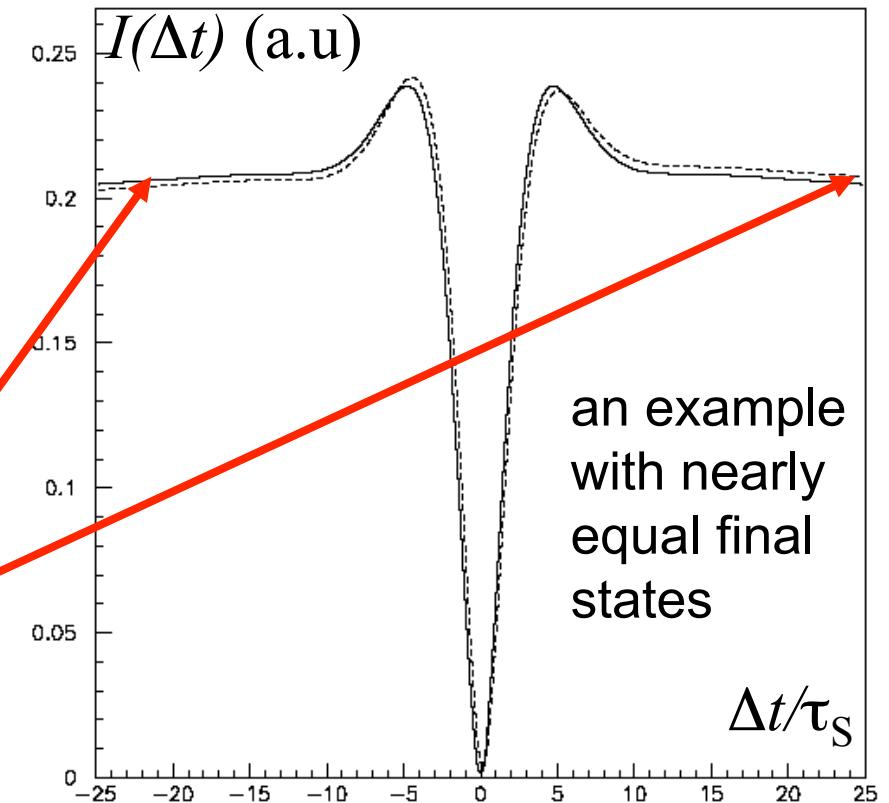
$$I(f_1, f_2; \Delta t) \propto \left\{ |\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} - 2|\eta_1||\eta_2| e^{-(\Gamma_S + \Gamma_L)\Delta t/2} \cos(\Delta m \Delta t + \phi_2 - \phi_1) \right\}$$



η_2/η_1
from the asymmetry at small Δt

$$\frac{|\eta_1|^2 - |\eta_2|^2}{|\eta_1|^2 + |\eta_2|^2}$$

from the asymmetry at large Δt

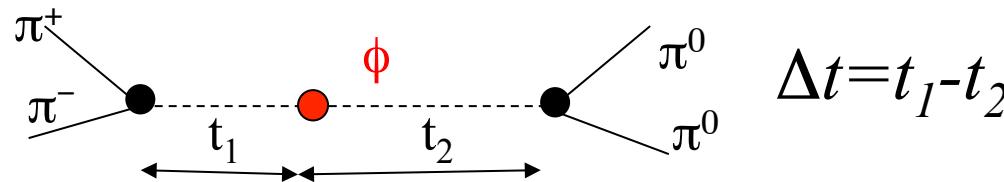


Exploiting neutral kaon interferometry

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

$$\eta_i = |\eta_i| e^{i\phi_i} = \langle f_i | T | K_L \rangle / \langle f_i | T | K_S \rangle$$

$$I(f_1, f_2; \Delta t) \propto \left\{ |\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} - 2|\eta_1||\eta_2| e^{-(\Gamma_S + \Gamma_L)\Delta t/2} \cos(\Delta m \Delta t + \phi_2 - \phi_1) \right\}$$



As an example

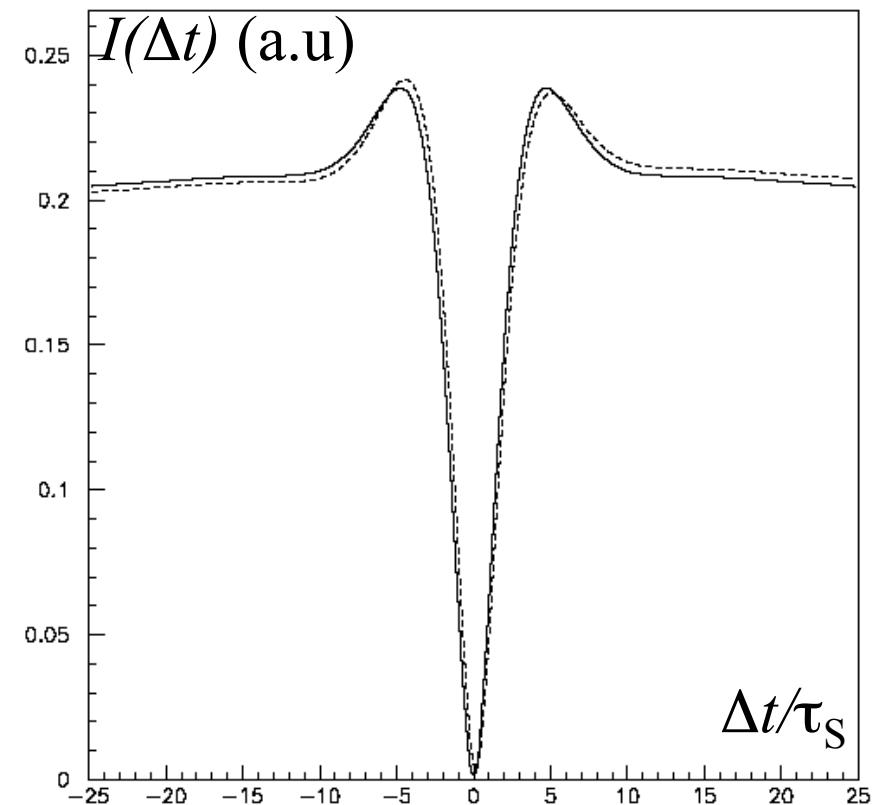
$f_1 = \pi^+ \pi^-$ $f_2 = \pi^0 \pi^0$

$$\eta_{+-} = \varepsilon \left(1 + \varepsilon' / \varepsilon \right)$$

$$\eta_{00} = \varepsilon \left(1 - 2\varepsilon' / \varepsilon \right)$$

$\Im(\varepsilon'/\varepsilon)$, $\Re(\varepsilon'/\varepsilon)$
from the asymmetry at small Δt

$\Re(\varepsilon'/\varepsilon)$
from the asymmetry at large Δt

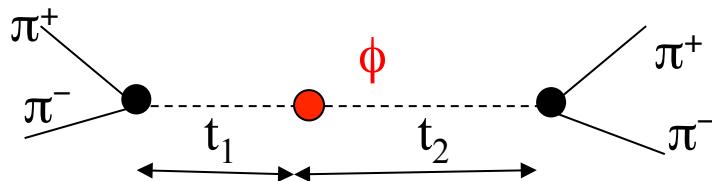


Exploiting neutral kaon interferometry

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

$$\eta_i = |\eta_i| e^{i\phi_i} = \langle f_i | T | K_L \rangle / \langle f_i | T | K_S \rangle$$

$$I(f_1, f_2; \Delta t) \propto \left\{ |\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} - 2|\eta_1||\eta_2| e^{-(\Gamma_S + \Gamma_L)\Delta t/2} \cos(\Delta m \Delta t + \phi_2 - \phi_1) \right\}$$



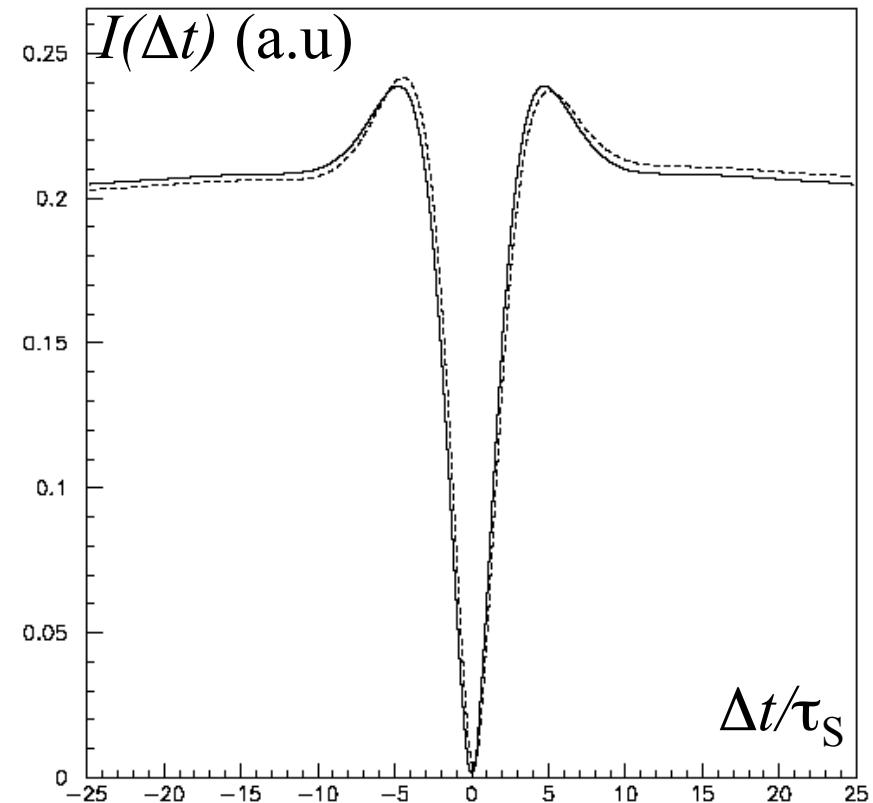
$$\eta_{+-}^{(1)} = \varepsilon \left(1 - \delta(+\vec{p}, t) / \varepsilon \right)$$

$$\eta_{+-}^{(2)} = \varepsilon \left(1 - \delta(-\vec{p}, t) / \varepsilon \right)$$

$$\Im(\Delta\delta/\varepsilon)$$

from the asymmetry at small Δt

$\Re(\Delta\delta/\varepsilon) \approx 0$ because $\Delta\delta \perp \varepsilon$
from the asymmetry at large Δt

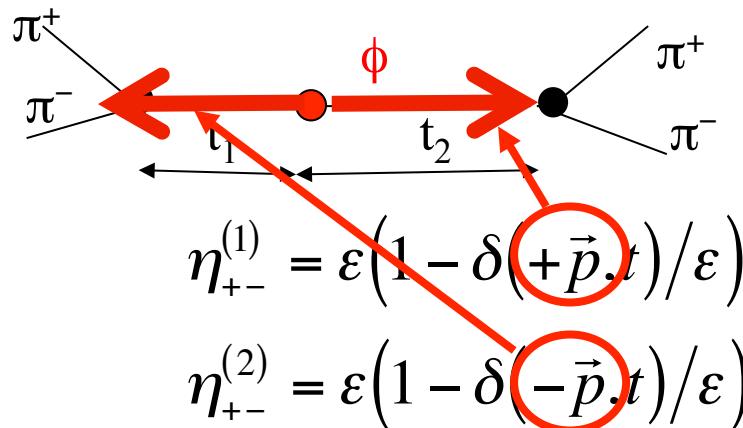


Exploiting neutral kaon interferometry

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

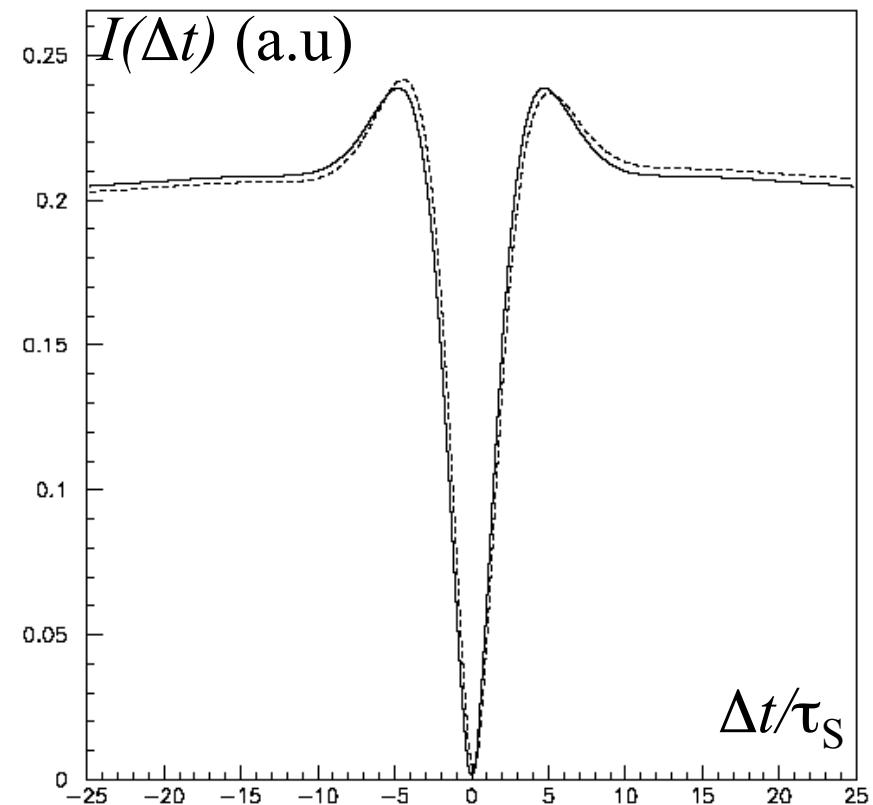
$$\eta_i = |\eta_i| e^{i\phi_i} = \langle f_i | T | K_L \rangle / \langle f_i | T | K_S \rangle$$

$$I(f_1, f_2; \Delta t) \propto \left\{ |\eta_1|^2 e^{-\Gamma_L \Delta t} + |\eta_2|^2 e^{-\Gamma_S \Delta t} - 2|\eta_1||\eta_2| e^{-(\Gamma_S + \Gamma_L)\Delta t/2} \cos(\Delta m \Delta t + \phi_2 - \phi_1) \right\}$$



$\Im(\Delta\delta/\epsilon)$
from the asymmetry at small Δt

$\Re(\Delta\delta/\epsilon) \approx 0$ because $\Delta\delta \perp \epsilon$
from the asymmetry at large Δt



Measurement of $\Delta a_{X,Y,Z}$ at KLOE

$\Delta a_{X,Y,Z}$ from $\phi \rightarrow K_S K_L \rightarrow \pi^+ \pi^- \pi^+ \pi^-$
 (analysis vs polar angle θ and sidereal time t ;
 integration in azimuthal angle ϕ)

$$I[\pi^+ \pi^- (\cos \theta > 0), \pi^+ \pi^- (\cos \theta < 0); \Delta t]$$

- at $\Delta t \sim \tau_s$ sensitive to $\text{Im}(\delta/\varepsilon)$

With $L=1 \text{ fb}^{-1}$ (preliminary): $\chi^2/\text{dof}=131/117$

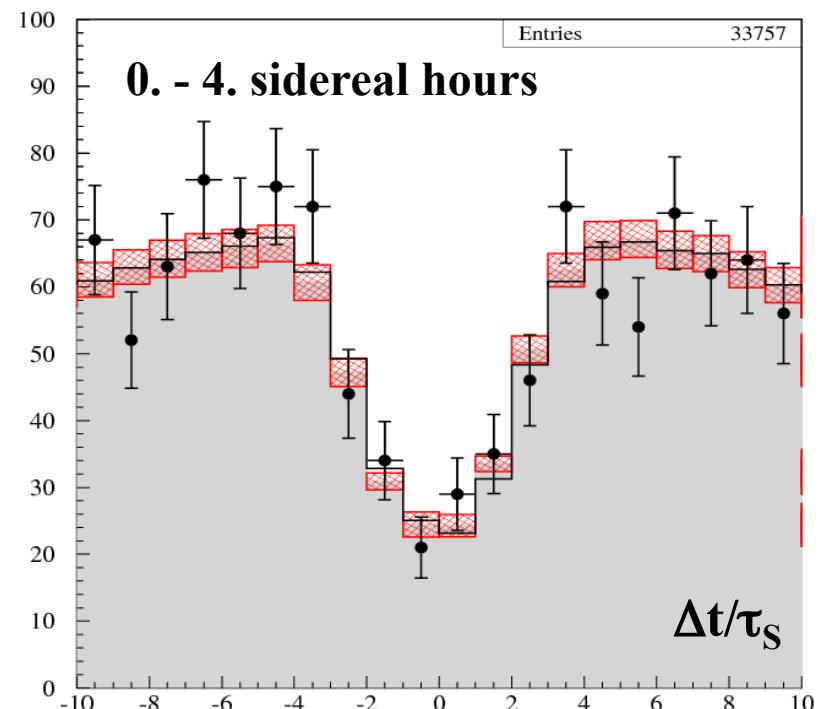
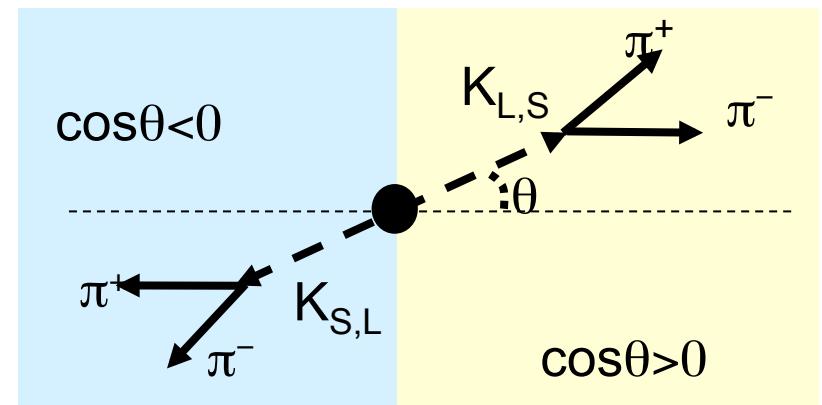
$$\Delta a_X = (-6.3 \pm 6.0) \times 10^{-18} \text{ GeV}$$

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

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

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

BABAR $\Delta a_{x,y}^B, (\Delta a_0^B - 0.30 \Delta a_Z^B) \sim O(10^{-13} \text{ GeV})$

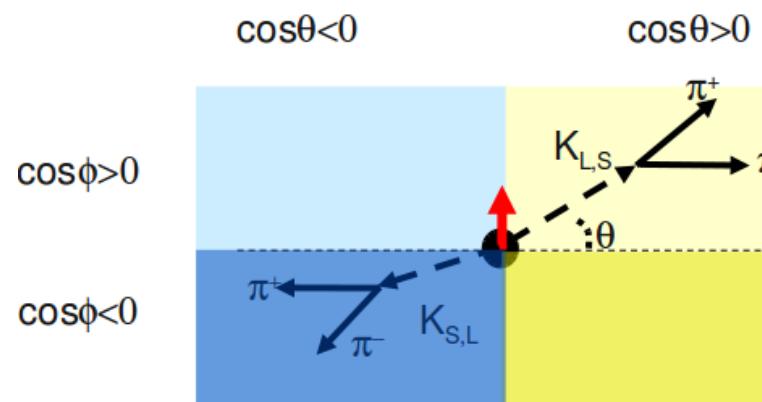
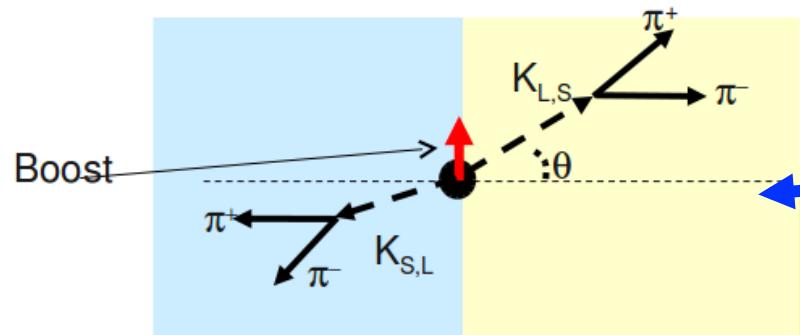


Refining method & techniques

$\cos\theta < 0$

$\cos\theta > 0$

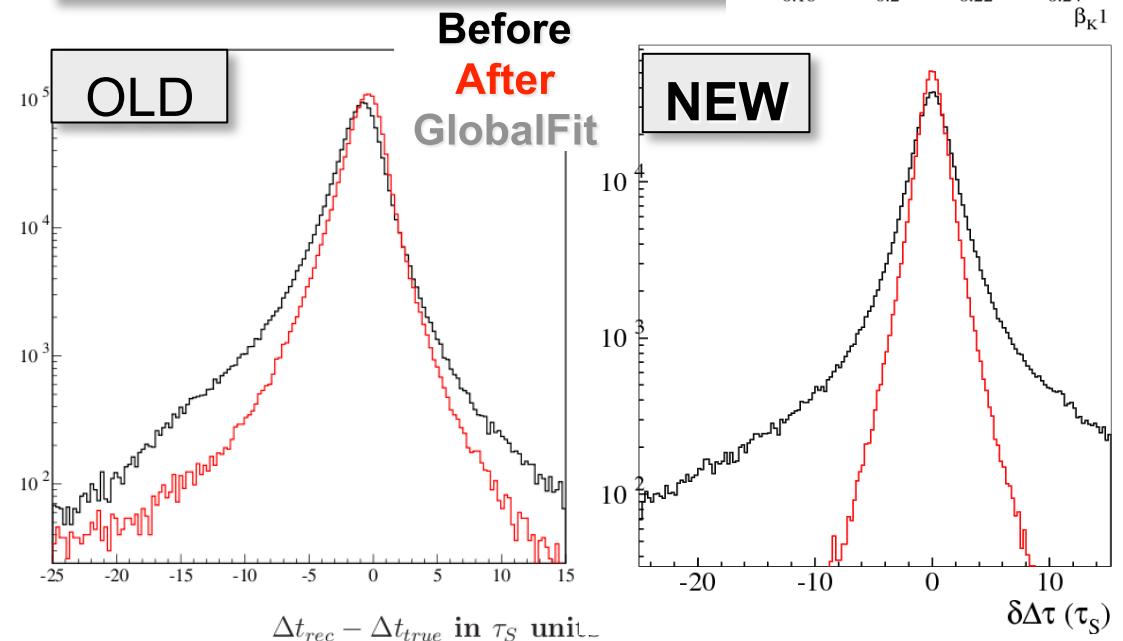
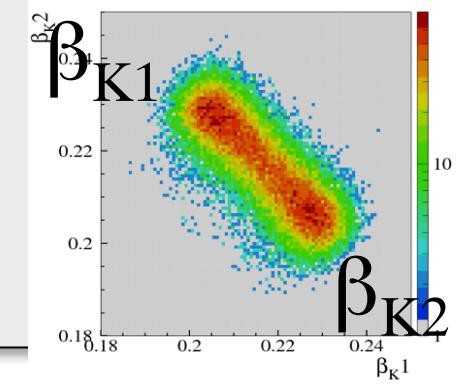
$$\delta = i \sin \phi_{SW} e^{i\phi_{SW}} \gamma_K (\Delta a_0 - \vec{\beta}_K \cdot \Delta \vec{a}) / \Delta m$$



Refined techniques used to select and analyse data:
improvement in the Δt resolution tails, and improved sensitivity on CPTV parameters

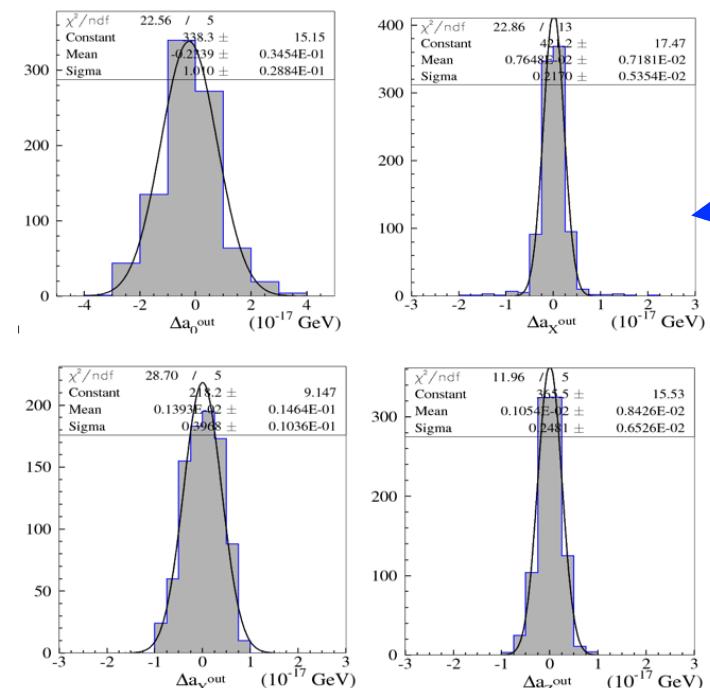
Possible effects due to Δa_0 are washed out in the simple **forward – backward analysis** (integration in ϕ).

The **quadrant analysis** (kaons with $\gamma_{K1} \neq \gamma_{K2}$) recovers sensitivity to Δa_0

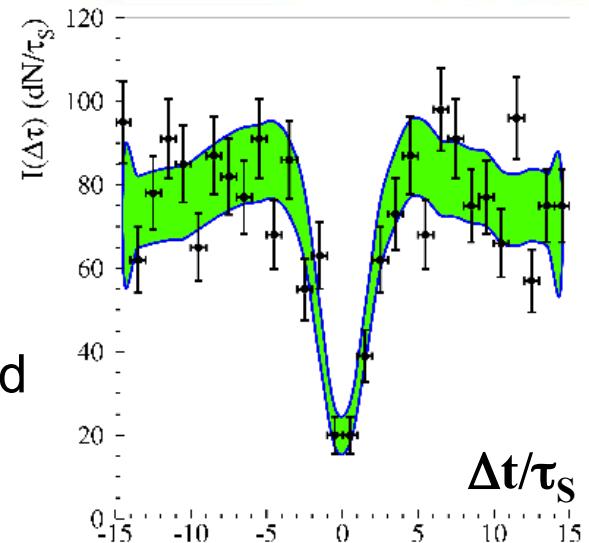


Refining method & techniques

The analysis is performed in
4 bins of sidereal time
 \times 2 bins for the ϕ quadrant of
the forward kaon
 \times 30 bins of Δt = 240 bins



Example:
1 bin sidereal time
(0-4 hours)
for quadrant
($\cos\theta>0 \cos\phi>0$).
Data: black points
Fit result: green band
(stat. err. only)



The expected sensitivity on the Δa_μ parameters with the full KLOE data set statistics has been evaluated with the MC simulation including data control samples for corrections data/MC:

$\Delta a_0 : \pm 1 \times 10^{-17} \text{ GeV}$

$\Delta a_{X,Y,Z} : \pm 2 \div 4 \times 10^{-18} \text{ GeV}$

We expect an improvement of a factor ~ 2 wrt KLOE preliminary results.

Perspectives and Conclusions

Prospects for KLOE-2 at upgraded DAΦNE

Param.	Present best published measurement	KLOE-2 L=5 fb ⁻¹	KLOE-2 L=10 fb ⁻¹	KLOE-2 L=20 fb ⁻¹
BR(K _S →3π ⁰)	< 1.2× 10 ⁻⁷	< 1.4× 10 ⁻⁸	< 7× 10 ⁻⁹	< 3× 10 ⁻⁹ - seen
A _S	(1.5 ± 11) × 10 ⁻³	± 2.7 × 10 ⁻³	± 1.9 × 10 ⁻³	± 1.4 × 10 ⁻³
A _L	(332.2 ± 5.8 ± 4.7) × 10 ⁻⁵	± 8.9 × 10 ⁻⁵	± 6.3 × 10 ⁻⁵	± 4.5 × 10 ⁻⁵
Re(ε' /ε)	(1.92 ± 0.21) × 10 ⁻³	± 0.72 × 10 ⁻³	± 0.51 × 10 ⁻³	± 0.36 × 10 ⁻³
Im(ε' /ε)	(-1.72 ± 2.02) × 10 ⁻³	± 9.4 × 10 ⁻³	± 6.7 × 10 ⁻³	± 4.7 × 10 ⁻³
Re(δ)+Re(x ₋)	Re(δ) = (0.25 ± 0.23) × 10 ⁻³ (*) Re(x ₋) = (-4.2 ± 1.7) × 10 ⁻³ (*)	± 0.7 × 10 ⁻³	± 0.5 × 10 ⁻³	± 0.4 × 10 ⁻³
Im(δ)+Im(x ₊)	Im(δ) = (-0.6 ± 1.9) × 10 ⁻⁵ (*) Im(x ₊) = (0.2 ± 2.2) × 10 ⁻³ (*)	± 9 × 10 ⁻³	± 7 × 10 ⁻³	± 5 × 10 ⁻³
Δm	(5.2797 ± 0.0195) × 10 ⁹ s ⁻¹	± 0.096 × 10 ⁹ s ⁻¹	± 0.068 × 10 ⁹ s ⁻¹	± 0.048 × 10 ⁹ s ⁻¹

(*) = PDG 2010 fit

Prospects for KLOE-2 at upgraded DAΦNE

Param.	Present best published measurement	KLOE-2 (IT) L=5 fb ⁻¹	KLOE-2 (IT) L=10 fb ⁻¹	KLOE-2 (IT) L=20 fb ⁻¹
ξ_{00}	$(0.1 \pm 1.0) \times 10^{-6}$	$\pm 0.26 \times 10^{-6}$	$\pm 0.18 \times 10^{-6}$	$\pm 0.13 \times 10^{-6}$
ξ_{SL}	$(0.3 \pm 1.9) \times 10^{-2}$	$\pm 0.49 \times 10^{-2}$	$\pm 0.35 \times 10^{-2}$	$\pm 0.25 \times 10^{-2}$
α	$(-0.5 \pm 2.8) \times 10^{-17} \text{ GeV}$	$\pm 5.0 \times 10^{-17} \text{ GeV}$	$\pm 3.5 \times 10^{-17} \text{ GeV}$	$\pm 2.5 \times 10^{-17} \text{ GeV}$
β	$(2.5 \pm 2.3) \times 10^{-19} \text{ GeV}$	$\pm 0.50 \times 10^{-19} \text{ GeV}$	$\pm 0.35 \times 10^{-19} \text{ GeV}$	$\pm 0.25 \times 10^{-19} \text{ GeV}$
γ	$(1.1 \pm 2.5) \times 10^{-21} \text{ GeV}$ compl. pos. hyp. $(0.7 \pm 1.2) \times 10^{-21} \text{ GeV}$	$\pm 0.75 \times 10^{-21} \text{ GeV}$ compl. pos. hyp. $\pm 0.33 \times 10^{-21} \text{ GeV}$	$\pm 0.53 \times 10^{-21} \text{ GeV}$ compl. pos. hyp. $\pm 0.23 \times 10^{-21} \text{ GeV}$	$\pm 0.38 \times 10^{-21} \text{ GeV}$ compl. pos. hyp. $\pm 0.16 \times 10^{-21} \text{ GeV}$
$\text{Re}(\omega)$	$(-1.6 \pm 2.6) \times 10^{-4}$	$\pm 0.70 \times 10^{-4}$	$\pm 0.49 \times 10^{-4}$	$\pm 0.35 \times 10^{-4}$
$\text{Im}(\omega)$	$(-1.7 \pm 3.4) \times 10^{-4}$	$\pm 0.86 \times 10^{-4}$	$\pm 0.61 \times 10^{-4}$	$\pm 0.43 \times 10^{-4}$
Δa_0	$[(0.4 \pm 1.8) \times 10^{-17} \text{ GeV}]$	$\pm 0.52 \times 10^{-17} \text{ GeV}$	$\pm 0.36 \times 10^{-17} \text{ GeV}$	$\pm 0.26 \times 10^{-17} \text{ GeV}$
Δa_Z	$[(2.4 \pm 9.7) \times 10^{-18} \text{ GeV}]$	$\pm 2.2 \times 10^{-18} \text{ GeV}$	$\pm 1.5 \times 10^{-18} \text{ GeV}$	$\pm 1.1 \times 10^{-18} \text{ GeV}$
$\Delta a_{X,Y}$	$[<10^{-21} \text{ GeV}]$	$\pm 1.3 \times 10^{-18} \text{ GeV}$	$\pm 0.95 \times 10^{-18} \text{ GeV}$	$\pm 0.67 \times 10^{-18} \text{ GeV}$

[....] = preliminary

Conclusions

- DAΦNE commissioning in progress
 - KLOE detector is fully operational
 - KLOE-2 upgrades are being completed
 - At KLOE-2 an improvement of about one order of magnitude in the precision of several CP/CPT symmetry tests is expected.
 - KLOE-2 physics program described in EPJC 68 (2010) 619-681
-
- In the meanwhile the analysis of the full KLOE data set is being completed:
 - New upper limit for $\text{BR}(K_S \rightarrow 3\pi^0)$. At KLOE-2 this analysis will benefit of the presence of low θ calorimeters QCALT- CCALT. With $O(10\text{fb}^{-1})$ it might be possible to have a first observation of the decay
 - A new method has been implemented to perform the CPT and Lorentz symmetry test. The analysis of the full KLOE data set analysis is almost completed. At KLOE-2 it will benefit of the new inner tracker detector improving Δt resolution, and of the new interaction region scheme with a doubled ϕ momentum (increasing the sensitivity to Δa_0).