Physics topics at KLOE-2

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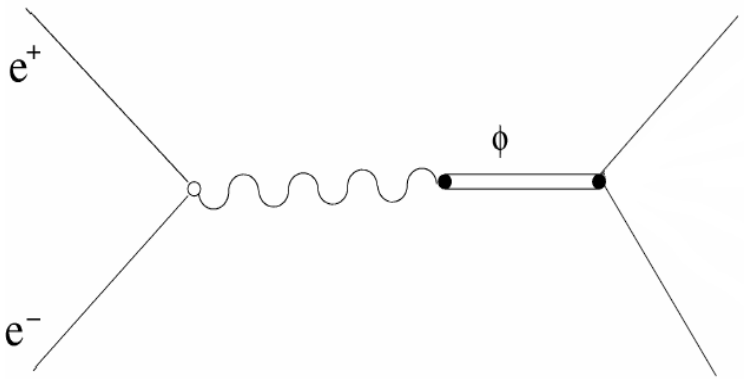
Outlook

- The DAFNE Φ-factory upgraded in luminosity
- KLOE detector setup
- From KLOE to KLOE-2
- Recent results and ongoing analysis
- Conclusions

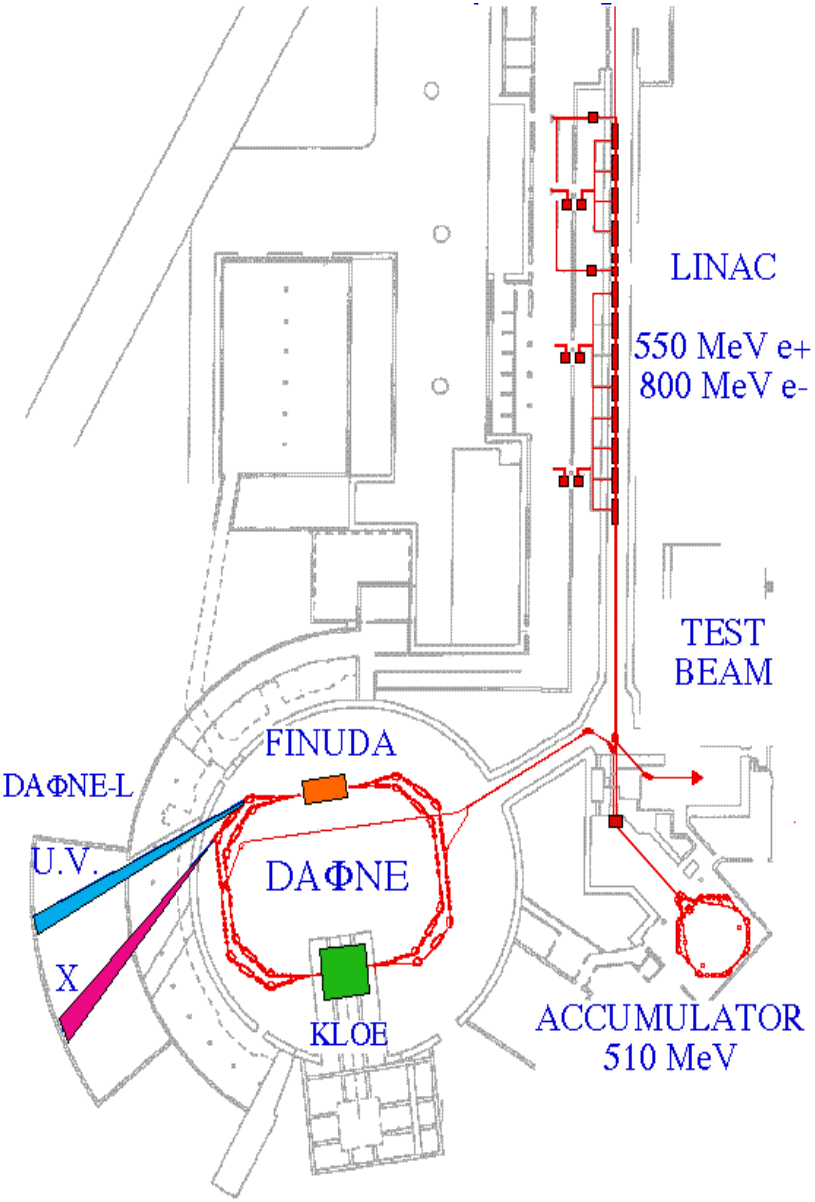
The DAFNE Φ-factory



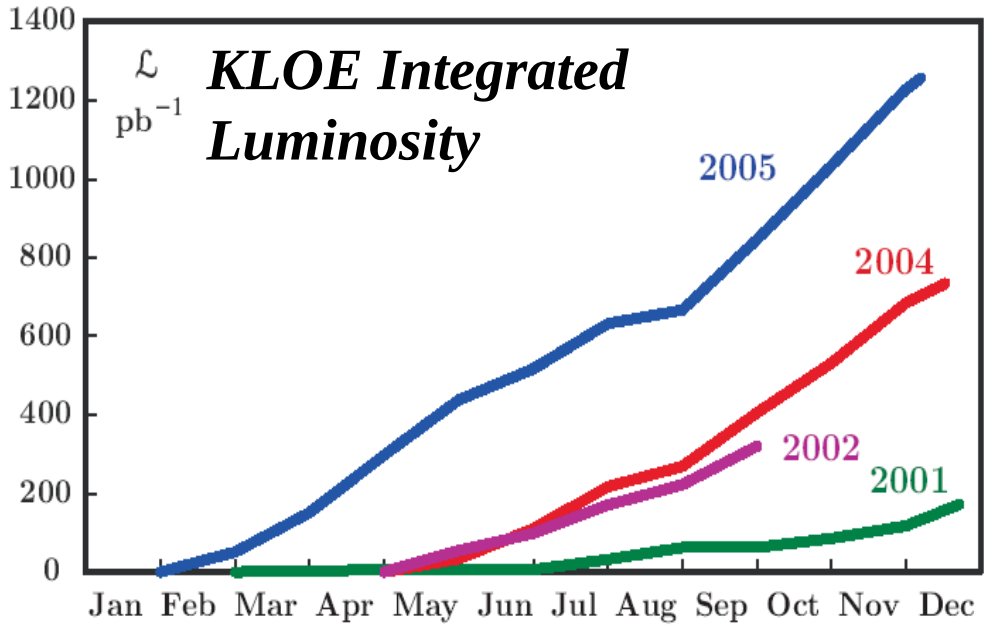
BR's for selected Φ decays	
K^+K^-	49.1%
K_SK_L	**34.1%**
$\rho\pi + \pi^+\pi^-\pi^0$	15.5%

- e^+e^- collider @ $\sqrt{s} = M_\phi = 1019.4$ MeV
- LAB momentum $p_\phi \sim 13$ MeV/c
- $\sigma_{peak} \sim 3$ μb
- Separate e^+e^- rings to reduce beam-beam interaction
- Beams crossing angle: 12.5 mrad
- Peak luminosity 1.5×10^{32} $cm^{-2}s^{-1}$

DAΦNE Luminosity history

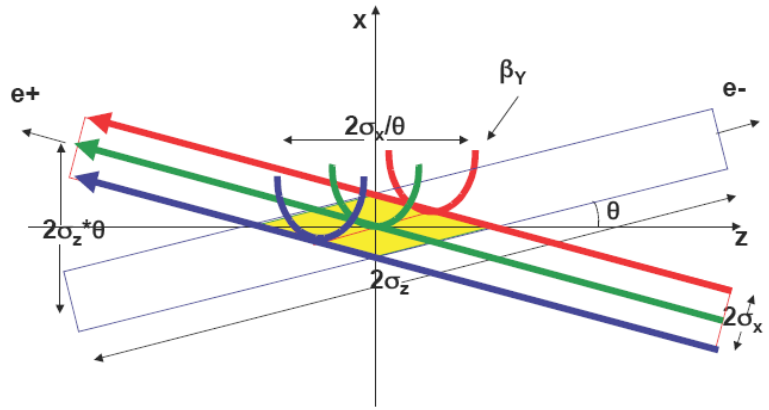


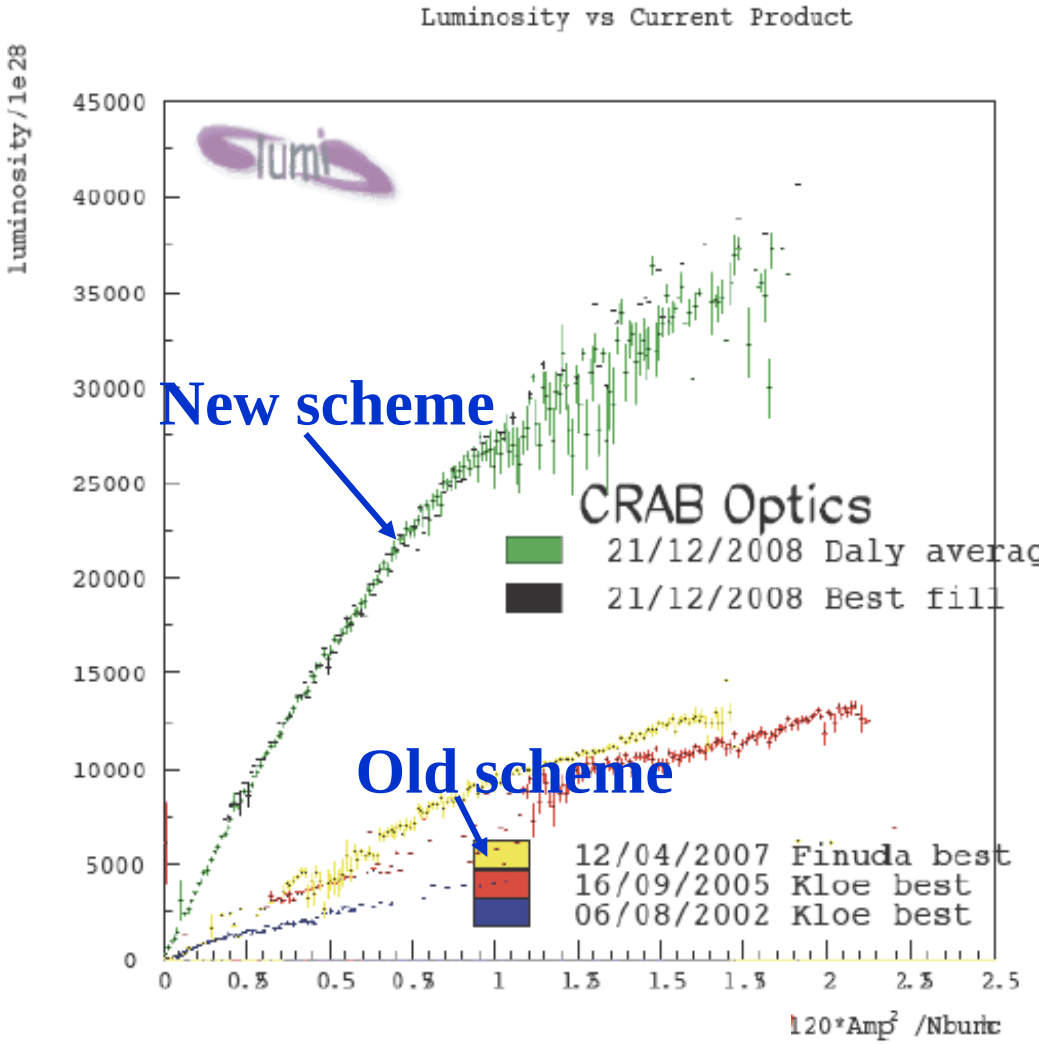
KLOE run:
Daily performance: 7-8 pb^{-1}
Best month $\int L\,dt \sim 200\ pb^{-1}$
Total KLOE $\int L\,dt \sim 2400\ pb^{-1}$ at ϕ mass peak + 250 pb^{-1} off peak (@ 1 GeV)



New interaction scheme implemented: large beam crossing angle + sextupoles for crabbed waist optics

- $L_{new} \sim 3 \times L_{old}$
- $\int L dt = 1\ pb^{-1}/hour$





KLOE (K LOng Experiment)

Large cylindrical drift chamber

- Uniform tracking and vertexing in all volume
- Helium based gas mixture (90% He – 10% $IsoC_4H_{10}$)
- Stereo wire geometry

$\sigma_p/p = 0.4\ \%$

$\sigma_{xy} = 150\ \mu m$; $\sigma_z = 2$ mm

$\sigma_{vtx} \sim 3$ mm

$\sigma(M_{\pi\pi}) \sim 1$ MeV

Lead/scintillating-fiber calorimeter

- Hermetical coverage
- High efficiency for low energy photons

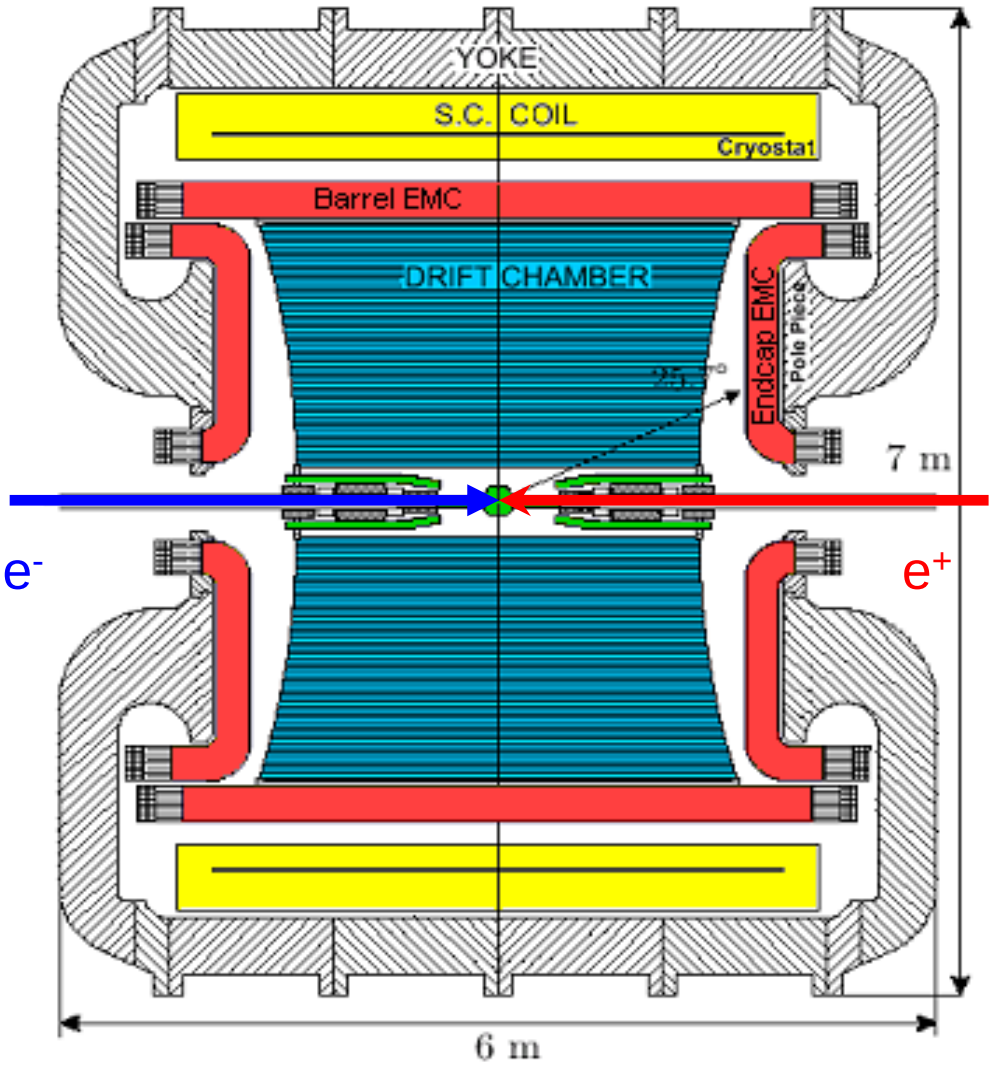
$\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$

$\sigma_t = 57\ ps / \sqrt{E(GeV)} \oplus 140\ ps$

$\sigma_{vtx}(\gamma\gamma) \sim 1.5$ cm

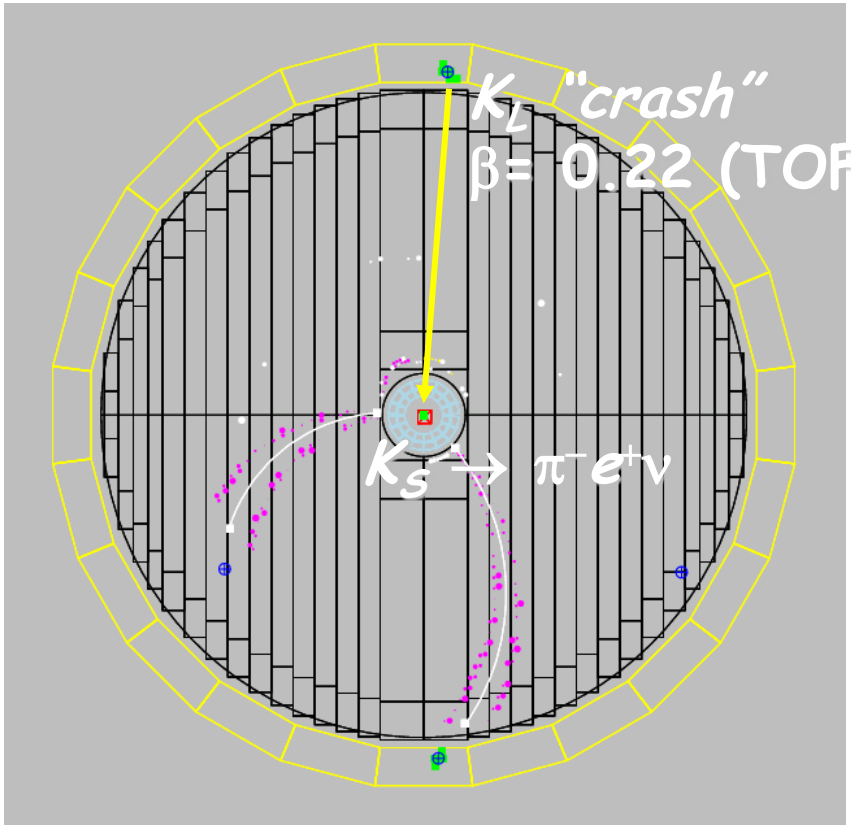
Superconducting coil

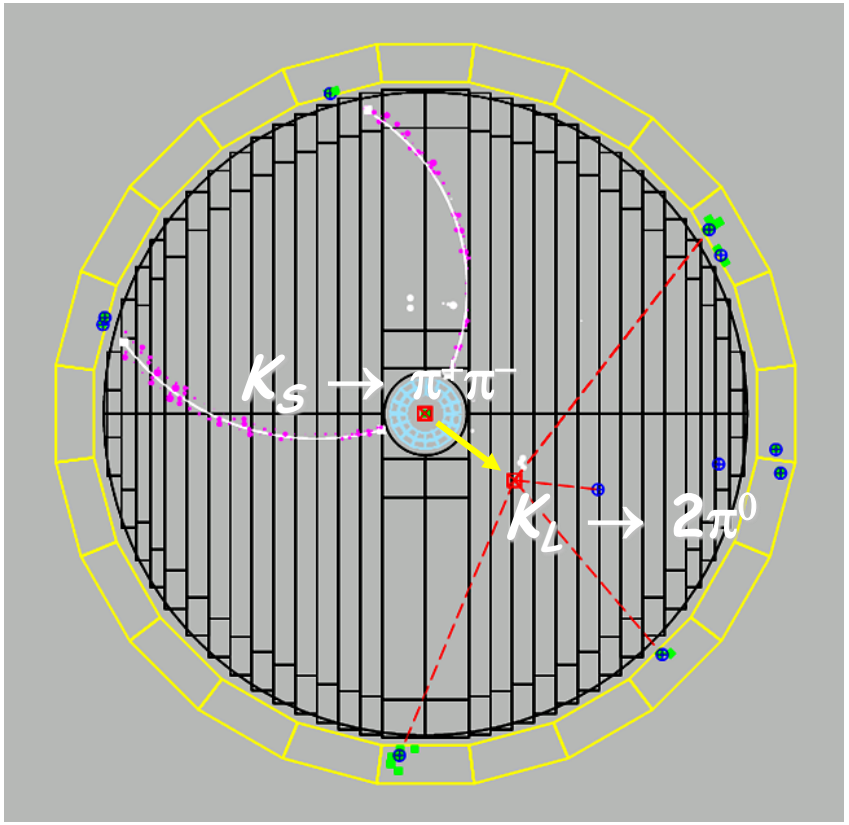
B = 0.52 T



K_S and K_L tagging

A Φ-factory offers the possibility to select pure kaon beams:



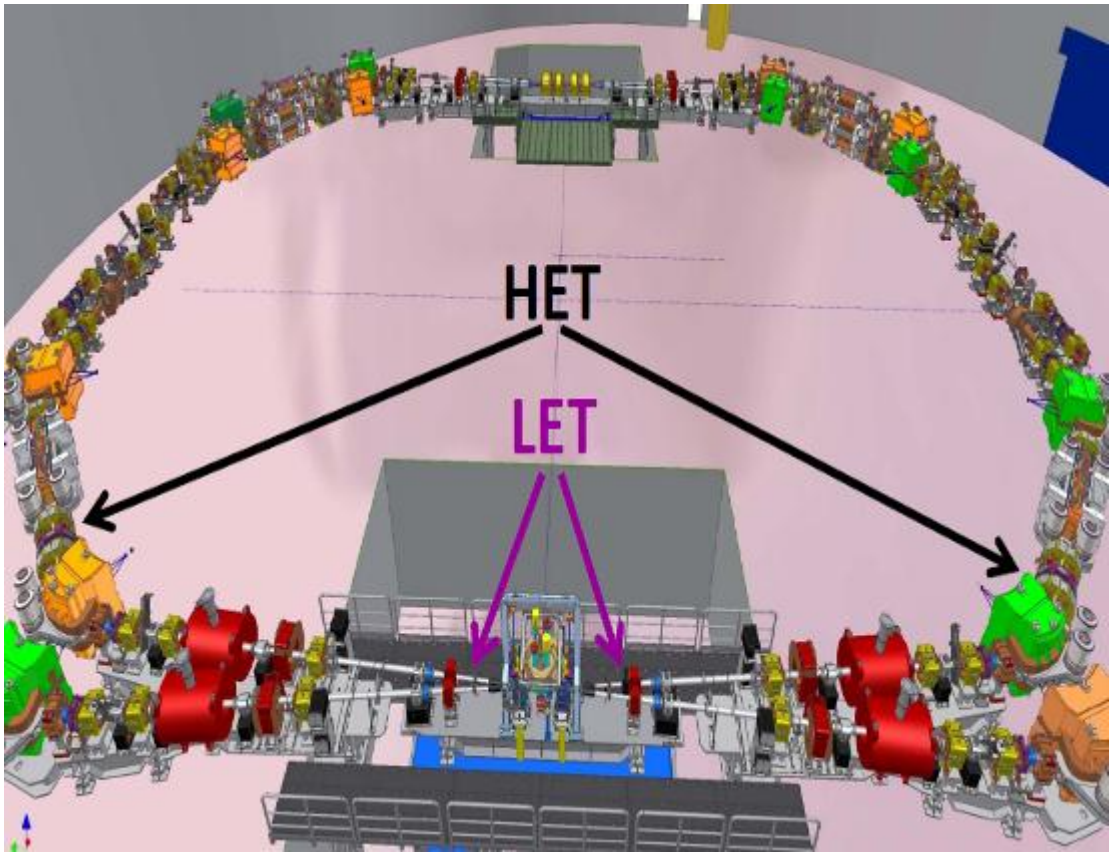


K_S tagged by K_L interaction in EmC
Efficiency ~ 30%
K_S angular resolution: ~ 1° (0.3° in φ)
K_S momentum resolution: ~ 2 MeV

K_L tagged by $K_S \rightarrow \pi^+\pi^-$ vertex at IP
Efficiency ~ 70%
K_L angular resolution: ~ 1°
K_L momentum resolution: ~ 2 MeV

From KLOE to KLOE-2: γγ taggers

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



LET: E_e ~ 160-230 MeV

- Inside KLOE detector
- LYSO+SiPM
- σ_E<10% for E>150 MeV

HET: E_e > 400 MeV

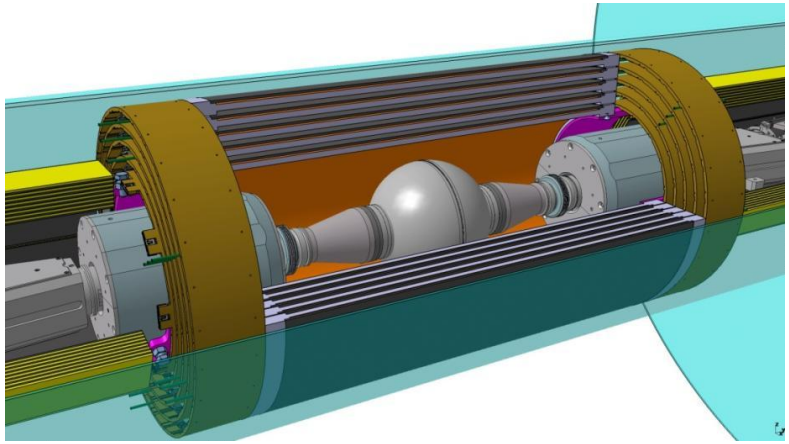
- 11 m from IP
- Scintillator hodoscopes
- σ_E ~ 2.5 MeV
- σ_T ~ 200 ps

γγ taggers are installed and ready for the first KLOE-2 run (STEP0) in autumn 2011
~ 5 fb^{-1} of integrated luminosity expected

Major detector upgrades for second KLOE-2 run (STEP1):

INNER TRACKER

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

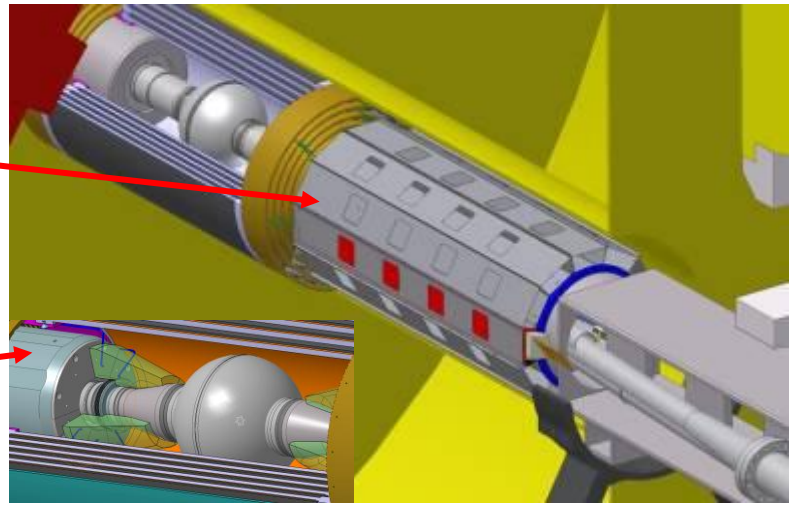


QCALT

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

CCALT

- LYSO + APD
- Increase acceptance for γ's from IP (21° →10°)



KLOE-2 Physics Program

Goal: **~20 fb^{-1} in the next 3-4 years** to extend the KLOE physics program **at DAΦNE upgraded in luminosity** (approved and funded):

[G.Amelino-Camelia et al., Eur. Phys. J. C 68 (2010), 619-681]

❖ **γγ physics**	➢ Existence (and properties) of σ/f_0(600) ➢ Study of Γ(S/PS→γγ) ➢ PS transition form factor
❖ **Light meson spectroscopy**	➢ Properties of scalar/vector mesons ➢ Rare η decays ➢ η′ physics
❖ **Kaon physics**	➢ Test of CPT (and QM) in correlated kaon decays ➢ Test of CPT in K_S semileptonic decays ➢ Test of SM (CKM unitarity, lepton universality) ➢ Test of ChPT (K_S decays)
❖ **Dark matter searches**	➢ Light bosons @ O(1 GeV)
❖ **Hadronic cross section**	➢ $\alpha_{em}(M_Z)$ and (g-2)

KLOE results in kaon physics

- **KLOE has measured all relevant inputs for charged and neutral kaons: BR's, lifetimes, form factors**
- **SM test in the flavor sector** through precise measurements of V_{us} and $R_K = \Gamma(K \to e\nu)/\Gamma(K \to \mu\nu)$
- **CPT and quantum mechanics tests** with the analysis of the QM interference of neutral kaons, K_s semileptonic decays, unitary (Bell-Steinberger relation)
- **Recent results and ongoing analysis**

✓ K_S lifetime
[Eur. Phys. J. C 71, 1604 (2011)]

✓ **$K_S \to \pi^0\pi^0\pi^0$** (preliminary result)

✓ **$K_SK_L \to \pi^+\pi^-\pi^+\pi^-$** (QM/CPT tests updated; further studies in progress)

✓ $K^+ \to \pi^+\pi^+\pi^-$

✓ K_S regeneration

✓ $K_SK_L \to \pi^+\pi^-\pi^0\pi^0$

✓ $K_SK_L \to \pi^+\pi^-\pi\ell\nu$

$K_L \to \pi e \nu$	0.4008 ± 0.0015 [50]
$K_L \to \pi \mu \nu$	0.2699 ± 0.0014 [50]
$K_L \to 3\pi^0$	0.1996 ± 0.0020 [50]
$K_L \to \pi^+\pi^-\pi^0$	0.1261 ± 0.0011 [50]
$K_L \to \pi^+\pi^-$	$(1.963 \pm 0.21) \times 10^{-3}$ [62]
$K_L \to \gamma\gamma$	$(5.569 \pm 0.077) \times 10^{-4}$ [63]
$K_S \to \pi^+\pi^-$	0.60196 ± 0.00051 [55]
$K_S \to \pi^0\pi^0$	0.30687 ± 0.00051 [55]
$K_S \to \pi e \nu$	$(7.05 \pm 0.09) \times 10^{-4}$ [54]
$K_S \to \gamma\gamma$	$(2.26 \pm 0.13) \times 10^{-6}$ [64]
$K_S \to 3\pi^0$	$<1.2 \times 10^{-7}$ at 90% C.L. [65]
$K_S \to e^+e^-(\gamma)$	$<9 \times 10^{-9}$ at 90% C.L. [66]
$K^+ \to \mu^+\nu(\gamma)$	0.6366 ± 0.0017 [52]
$K^+ \to \pi^+\pi^0(\gamma)$	0.2067 ± 0.0012 [53]
$K^+ \to \pi^0 e^+ \nu(\gamma)$	0.04972 ± 0.00053 [51]
$K^+ \to \pi^0 \mu^+ \nu(\gamma)$	0.03237 ± 0.00039 [51]
$K^+ \to \pi^+\pi^0\pi^0$	0.01763 ± 0.00034 [67]

$R_K = (2.493 \pm 0.025_{stat} \pm 0.019_{syst}) \times 10^{-5}$

$|V_{us}| = 0.2253 \pm 0.0007$ JHEP04(2008)059

$\tau_S = 89.562 \pm 0.029_{stat} \pm 0.043_{syst}$ [ps]

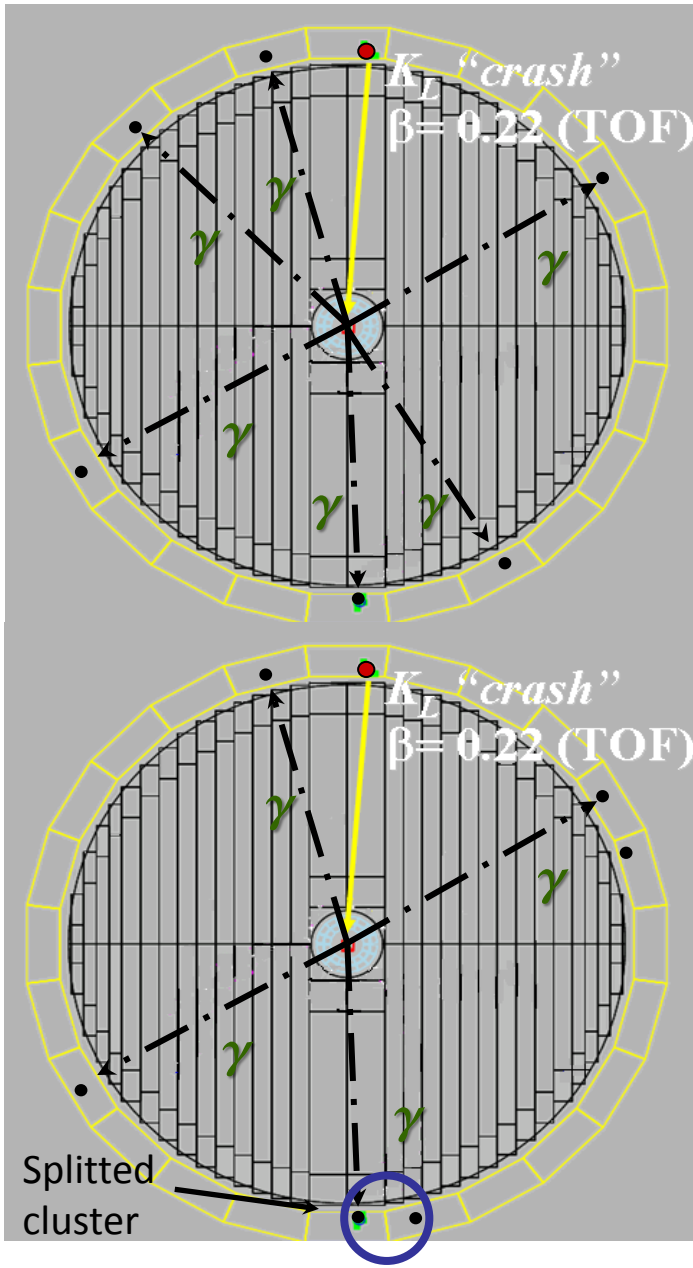
Search for $K_S \to \pi^0\pi^0\pi^0$

- The direct CP violation studies
- Test of the SM
- $\Gamma(K_S \to 3\pi^0) = \Gamma(K_L \to 3\pi^0)\,|\eta_{000}|^2$
  $\Rightarrow$ BR$\sim 2\times10^{-9}$
- Best sensitivity from KLOE
  450 pb^{-1} $\Rightarrow$ BR($K_S \to 3\pi^0$)$< 1.2 \times 10^{-7}$ @ 90%
  [PLB619(2005)61]
- K_L interactions in the calorimeter tag K_s decay
- 6 prompt photons required
- Dominant background from $K_S \to 2\pi^0$ + 2 split or 2 accidental clusters
- **The updated analysis:**

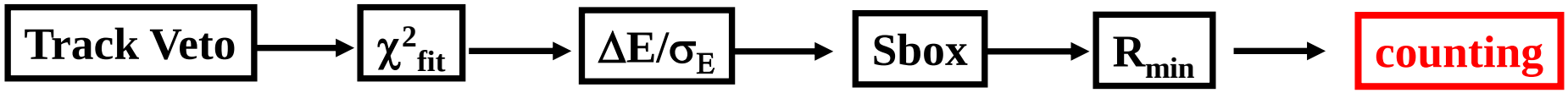
✓ improved clustering procedure to reduce split clusters

✓ hardening the β_{cr}* and energy cuts for K_s tagging

✓ processing the entire data set ($\sim 8\cdot10^9$ K_sK_L pairs)



Search for $K_S \rightarrow \pi^0\pi^0\pi^0$



- **Track Veto**

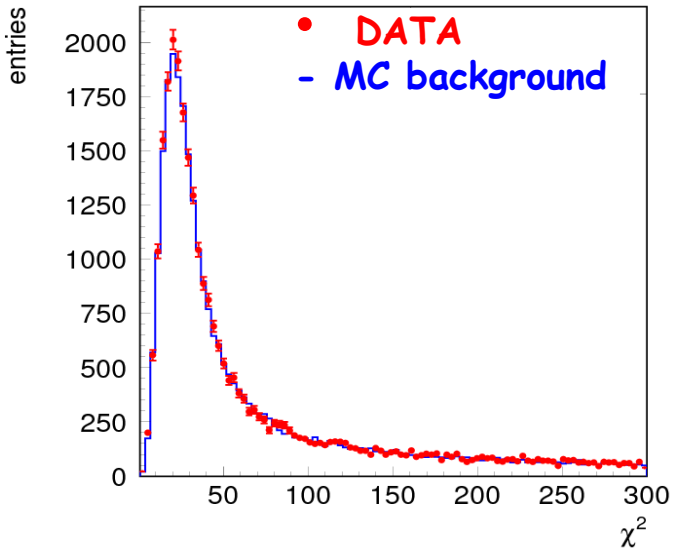
  events with at least one track from the Interaction Point (ρ_{PCA} < 4 cm & $|z_{PCA}|$ < 10 cm)

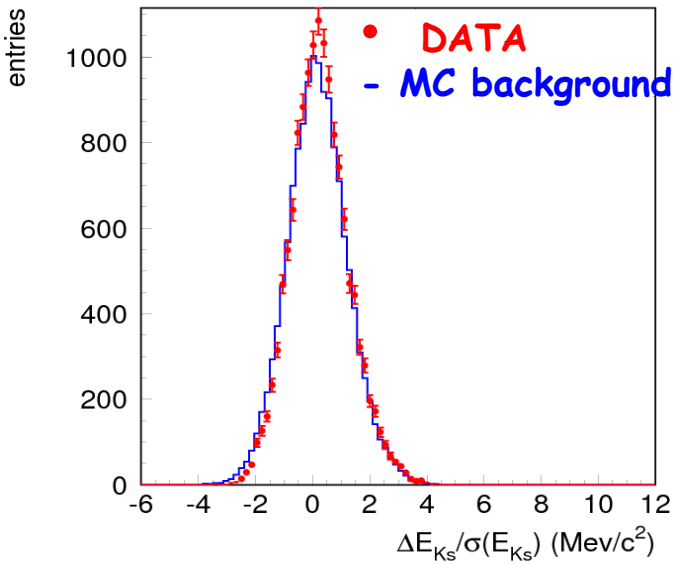
- **Kinematical fit**

  K_S mass, total 4-momentum conservation, consistency between the measured time and position of each cluster

- **$\Delta E/\sigma_E$ cut**

  $\Delta E = E_{Ks} - \Sigma E_\gamma$





Search for $K_S \to \pi^0\pi^0\pi^0$

Signal region definition

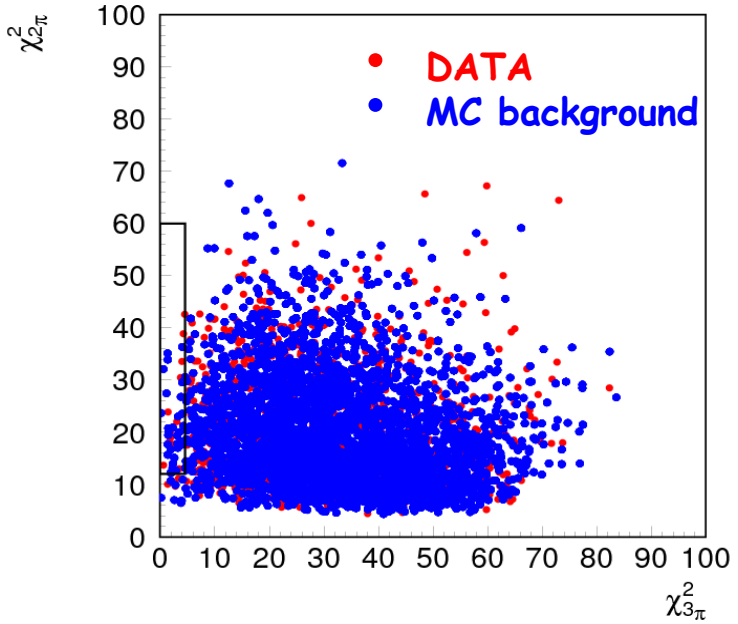
$\chi^2_{2\pi}$: pairing of 4 out of 6 photons

(π^0 masses, E_{Ks}, P_{Ks}, angle between π^0's)

$\chi^2_{3\pi}$: pairing of 6 clusters with best π^0 mass estimates

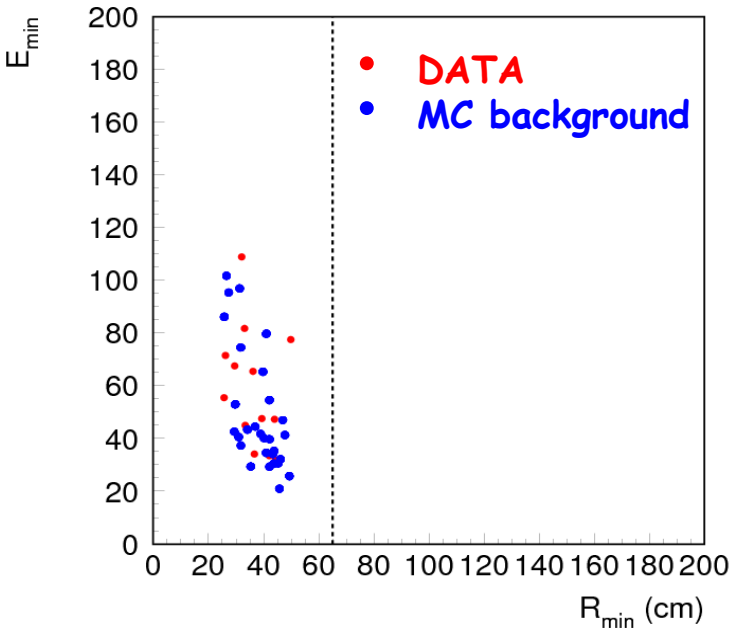
$$\chi^2_{2\pi} = \frac{\left(M_{\pi_1} - M_{pdg}\right)^2}{\sigma^2_{\pi_1}} + \frac{\left(M_{\pi_2} - M_{pdg}\right)^2}{\sigma^2_{\pi_2}} + \frac{\left(E_{K_S} - \sum E_{\gamma_i}\right)^2}{\sigma^2_E}$$
$$+ \frac{\left(P^x_{K_S} - \sum P^x_{\gamma_i}\right)^2}{\sigma^2_{P^x}} + \frac{\left(P^y_{K_S} - \sum P^y_{\gamma_i}\right)^2}{\sigma^2_{P^y}} + \frac{\left(P^z_{K_S} - \sum P^z_{\gamma_i}\right)^2}{\sigma^2_{P^z}} + \frac{\left(\pi - \vartheta_{\pi\pi}\right)^2}{\sigma^2_{\vartheta_{\pi\pi}}}$$

$$\chi^2_{3\pi} = \sum_{i=1}^{3} \frac{\left(M_{\pi_i} - M_{pdg}\right)^2}{\sigma^2_{\pi_i}}$$



R_{min}

The minimum distance between clusters



Search for $K_S \to \pi^0\pi^0\pi^0$

- Using the following set of cuts:

$E_{cr} > 129$ MeV
$0.196 \le \beta_{cr} \le 0.25$
} $\varepsilon_{cr} \approx 28\%$

$\chi^2_{fit} < 35$
$\Delta E/\sigma_E \ge 1.7$
$12.1 \le \chi^2_{2\pi} \le 60$
$\chi^2_{3\pi} \le 4.6$
$R_{min} > 65$ cm
} $\varepsilon_{3\pi} = \mathbf{0.19 \pm 0.012}$

We count $N_{obs} = 0$ **event selected as a signal and** $N_{exp} = 0$ **events in MC**

- **SM prediction:** 1 event after tagging ⇒ 0.19 after selection
- The selection efficiency for $K_S \to 2\pi^0$ decay: $\varepsilon_{2\pi} \sim 0.66$
- Upper limit on signal events: $N_{3\pi} < 2.44/\ \varepsilon_{3\pi} = 12.84$ (90% C.L.)
- Normalization sample: $N_{2\pi} = 90062000/\ \varepsilon_{2\pi} = 136457576$

PRELIMINARY

$$BR(K_S \to 3\pi^0) = \frac{N_{3\pi}/\varepsilon_{3\pi}}{N_{2\pi}/\varepsilon_{2\pi}} \times BR(K_S \to 2\pi^0) < 2.9 \times 10^{-8}$$

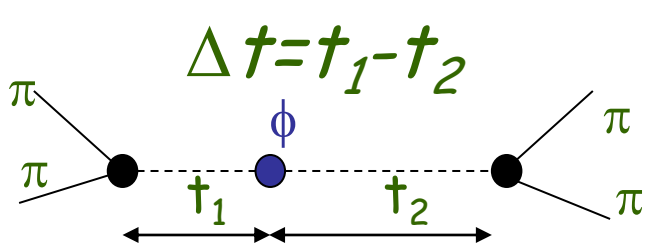
PRELIMINARY

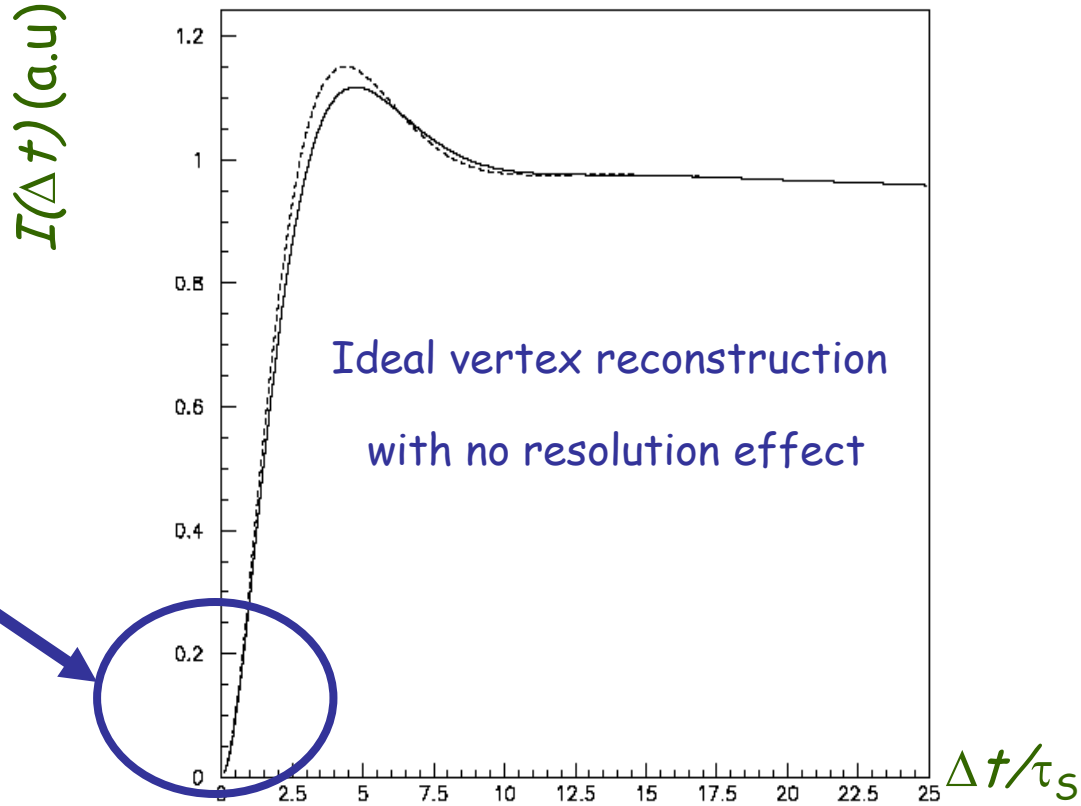
This result points to the feasibility of the first observation at KLOE-2

Kaon interferometry: $\Phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$

- Study of interference with neutral kaon pairs at the Φ -factory : a probe of CPT symmetry and QM at the Planck scale
- The interference pattern can be measured thanks to the fact that $\Delta m \sim \frac{1}{2}\,\Gamma_s$

$$I\left(\pi^+\pi^-,\pi^+\pi^-;|\Delta t|\right) \propto \left\{e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2\cdot e^{-(\Gamma_S+\Gamma_L)|\Delta t|/2}\cos\left(\Delta m|\Delta t|\right)\right\}$$





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

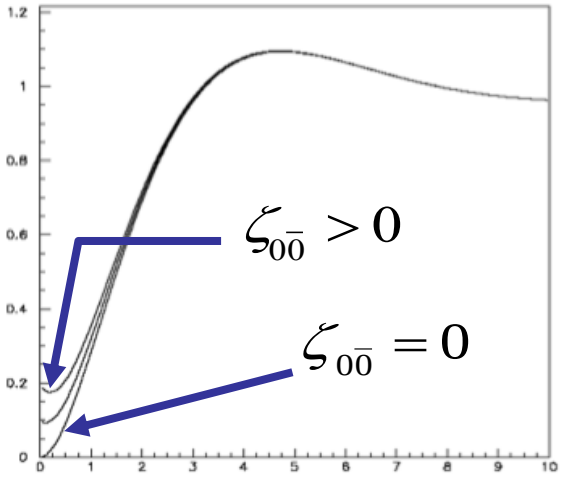
Decoherence and CPT in neutral Kaon system

$$I(\pi\pi,\pi\pi;|\Delta t|) \propto e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2\cdot(1-\zeta)\cdot e^{-(\Gamma_S+\Gamma_L)|\Delta t|/2}\cos(\Delta m|\Delta t|)$$

Modified interference term introducing a decoherence parameter ζ.

$\zeta_{00} = 0 \quad \rightarrow \quad$ QM

$\zeta_{00} = 1 \quad \rightarrow \quad$ total decoherence

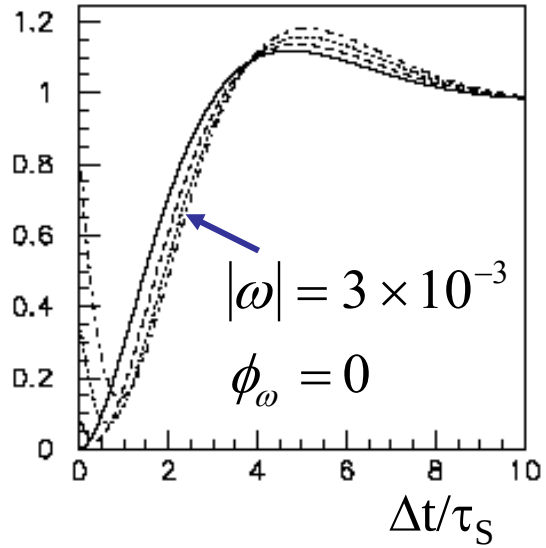


$I(\pi^+\pi^-, \pi^+\pi^-;\Delta t)$ (a.u.)

Quantum Gravity could also imply at Planck scale modified particle/antiparticle states:

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

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



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

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

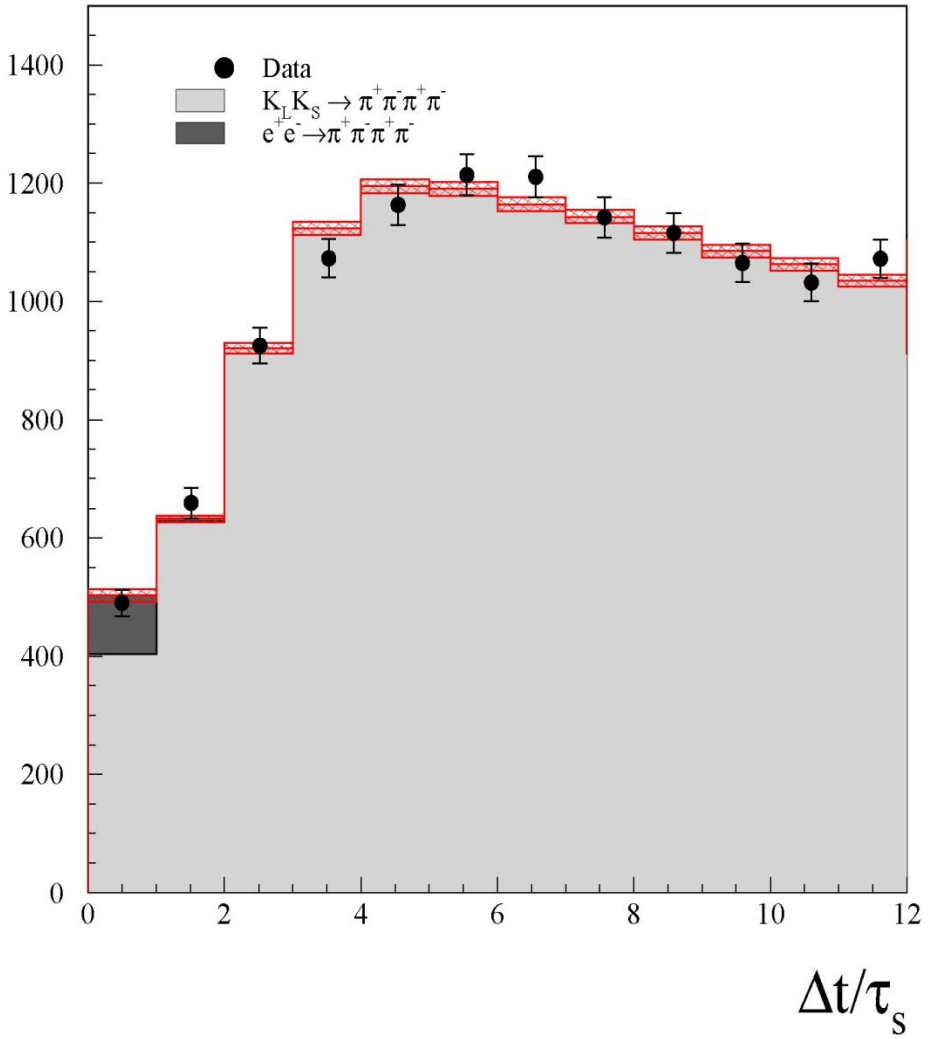
$$\zeta_{00} = \left(1.4 \pm 9.5_{\mathrm{STAT}} \pm 3.8_{\mathrm{SYST}}\right) \times 10^{-7}$$

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

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

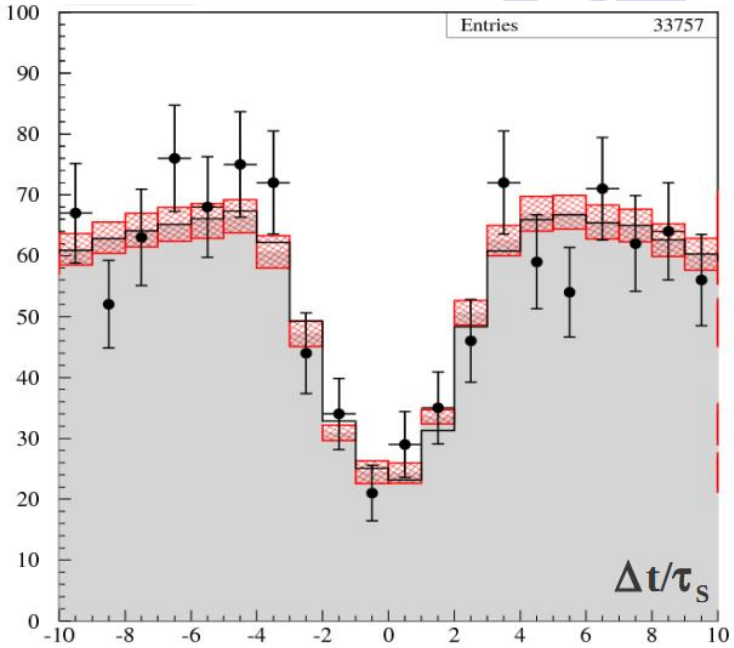
$$|\omega| < 1.0 \times 10^{-3} \quad \text{at} \quad 95\%\ \text{C.L.}$$

J.Phys.Conf.Ser.171:012008,2009.

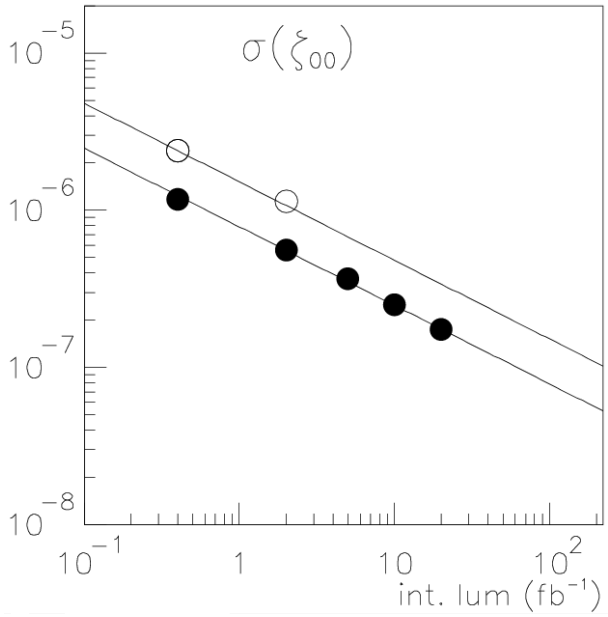


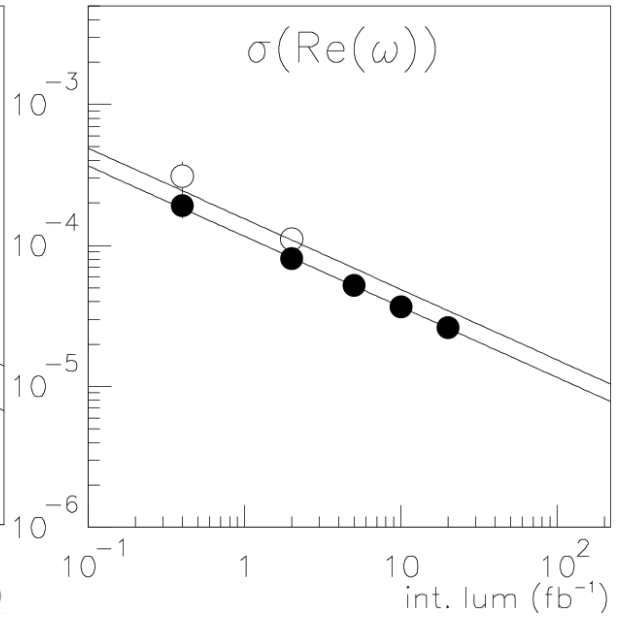
$\Phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+\pi^-$: test of quantum coherence

- Refined analysis of the $\Phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+\pi^-$ process is in progress
  - ✓ Symmetric event selection to avoid systematic asymmetries
  - ✓ Global fit of the event using geometrical relation to improve the resolution on the decay length **(additional quality request)**
- **KLOE-2: increased statistics (x4 in Step0) & improved resolution in the vertex reconstruction (x3 in Step1 with Inner Tracker)**



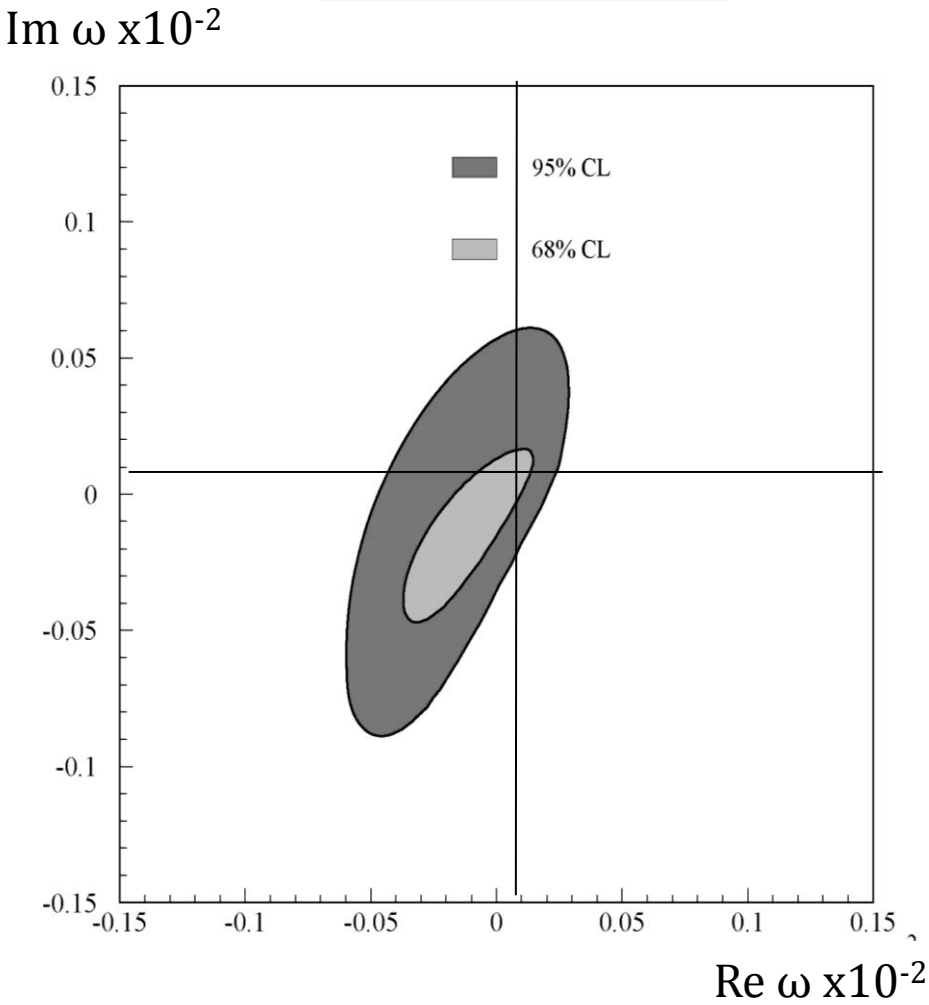
- ○ sensitivity with the present KLOE resolution ($\sigma(\Delta t) \approx \tau_S$)
- ● sensitivity with improved resolution ($\sigma(\Delta t) \approx 0.3\ \tau_S$ expected)



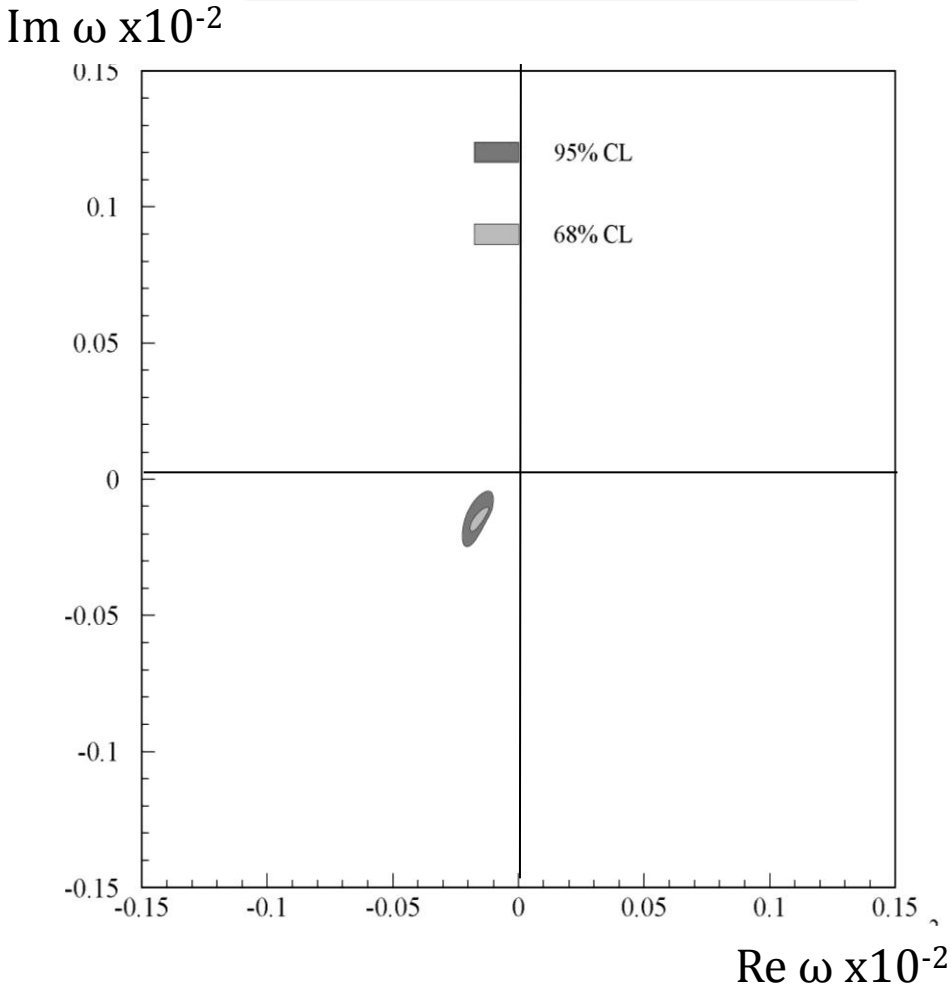


$\Phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+\pi^-$: test of quantum coherence

PRESENT KLOE



ACHIEVABLE AT KLOE-2



Conclusions

- KLOE is a high precision experiment which allowed detailed studies of both kaons and light scalar mesons to be done, as well as to test conservation of the CP, CPT and low energy QCD
- Ongoing analysis on kaons:
  - the best upper limit on BR($K_s \to 3\pi^0$) $\leq 2.9\ 10^{-8}$ (pointing to the feasibility of the first observation at KLOE-2)
  - From the analysis of the neutral kaon pairs, stringent constraints, at the Planck scale, on decoherence/CPT violation
- KLOE-2 @ Upgraded DAϕNE:

✓ STEP0: LET & HET installed,~ 5 fb^{-1} of integrated luminosity expected;

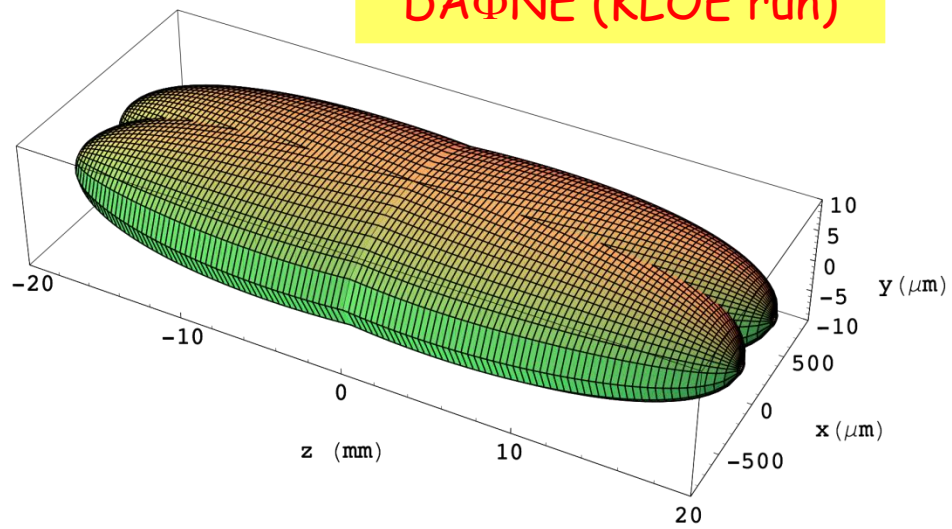
✓ STEP1: improved tracking with the Inner Tracker and improved photon acceptance with the calorimeters in the final focusing region (installation by the end of 2012); Data taking campaign during 2013-15 for a total of about 20 fb^{-1} integrated luminosity.

THANK YOU FOR ATTENTION

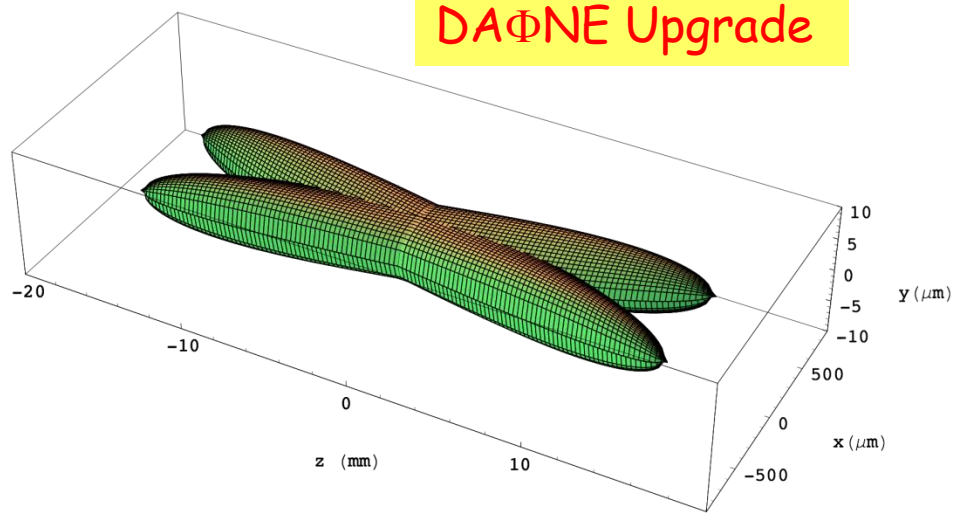
SPARES

DAΦNE upgrade

DAΦNE (KLOE run)

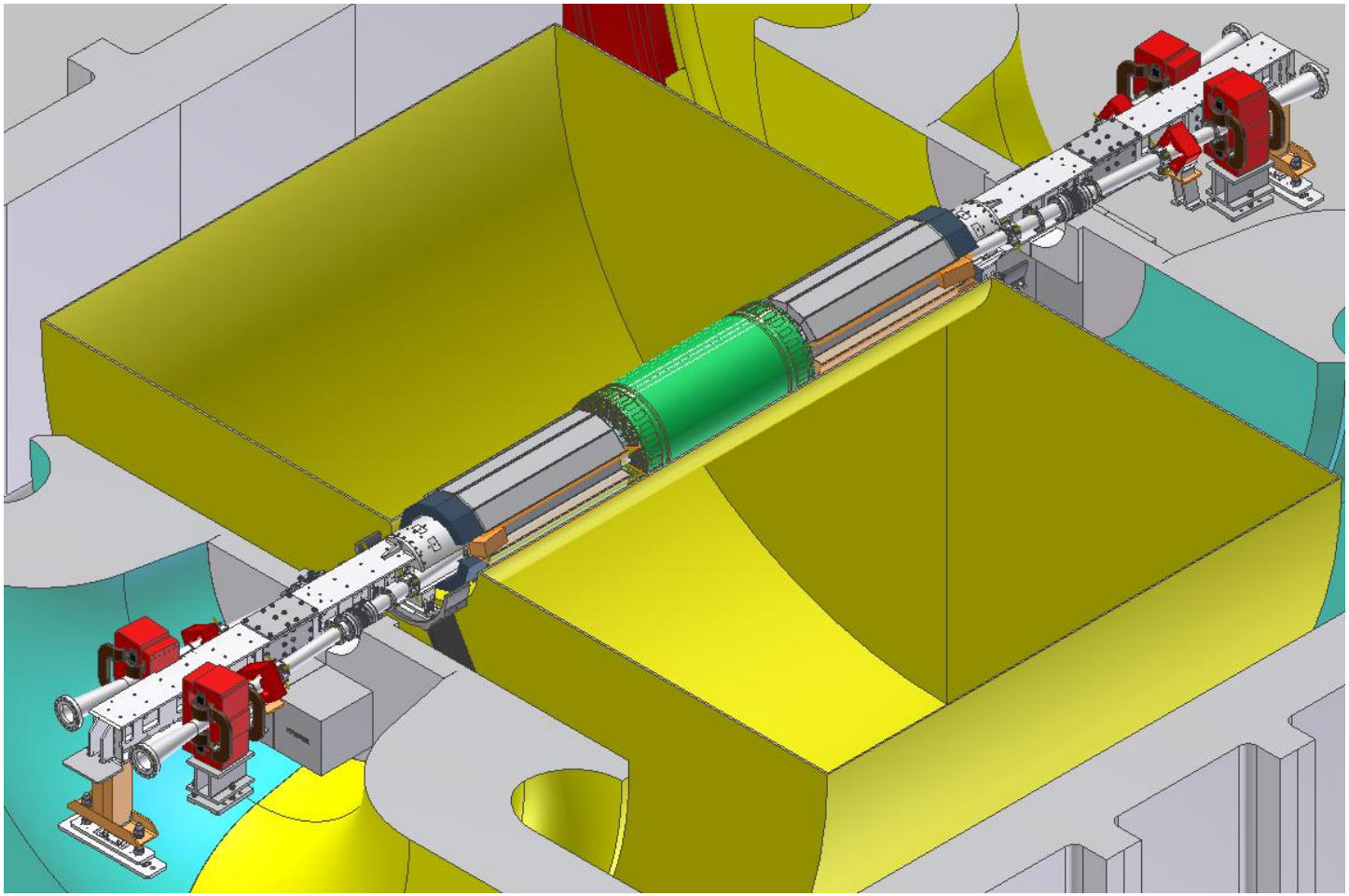


DAΦNE Upgrade

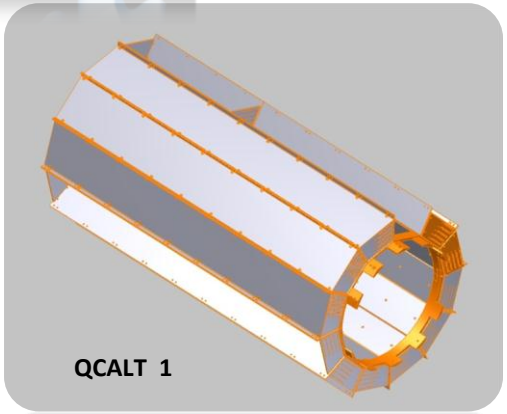


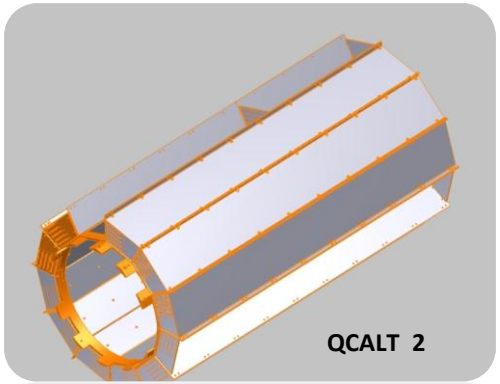
	DAΦNE (KLOE run)	DAΦNE Upgrade
I_{bunch} (mA)	13	13
N_{bunch}	110	110
β_y^* (cm)	1.7	0.65
β_x^* (cm)	170	20
σ_y^* (μm)	7	2.6
σ_x^* (μm)	700	200
σ_z (mm)	25	20
θ_{cross} (mrad) (half)	12.5	25
$\Phi_{Piwinski}$	0.45	2.5
L ($cm^{-2}s^{-1}$)	1.5×10^{32}	$>5 \times 10^{32}$

KLOE-2 upgrades

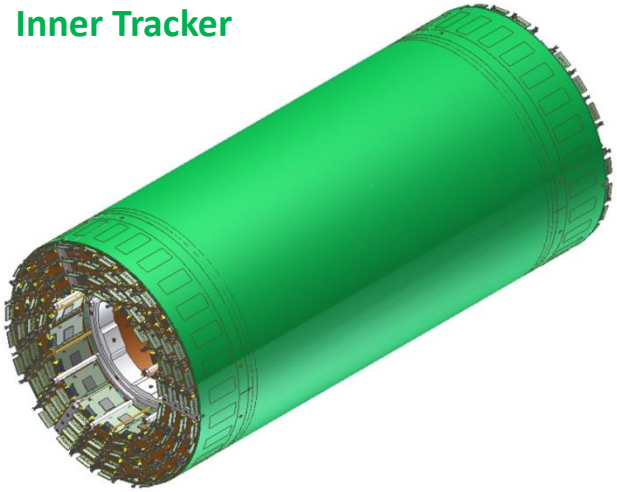


7 New Detecors to be integrated inside Kloe



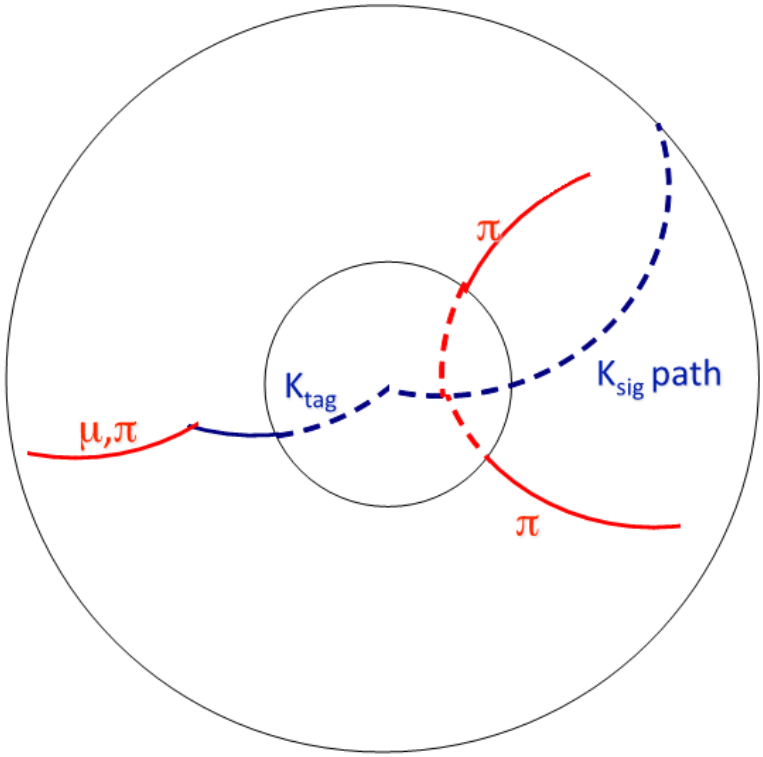


Inner Tracker



$K^+ \to \pi^+\pi^+\pi^-$ analysis

- Measurement of the absolute BR, to complete the program of precise measurement of the dominant $K^\pm$ decay channels
- Previous measurement : Chiang ('72) (2330 evts) BR = (5.56 ± 0.20)% [PDG fit : BR = (5.59 ± 0.04) %]



- **<u>Analysis strategy:</u>**
  - tag with $K \to \mu\nu$
  - 2 tracks with vertex along the K path before the DC wall
  - K path from the extrapolation of the Ktag to the Interaction Point
  - signal peak in the missing mass distribution (3rd pion)
  - control of the selection efficiency by reconstructing $K^+ \to \pi^- X$

$K^+ \to \pi^+\pi^+\pi^-$ analysis

- Analyzed sample: 174 pb^{-1}
- Efficiency evaluated from MC and corrected for data-MC discrepancies measured with $K^+ \to \pi^- X$ control sample: $\varepsilon_{sel} \sim 7\%$
- Signal obtained from a fit using MC shapes
- BR relative precision: 0.6%