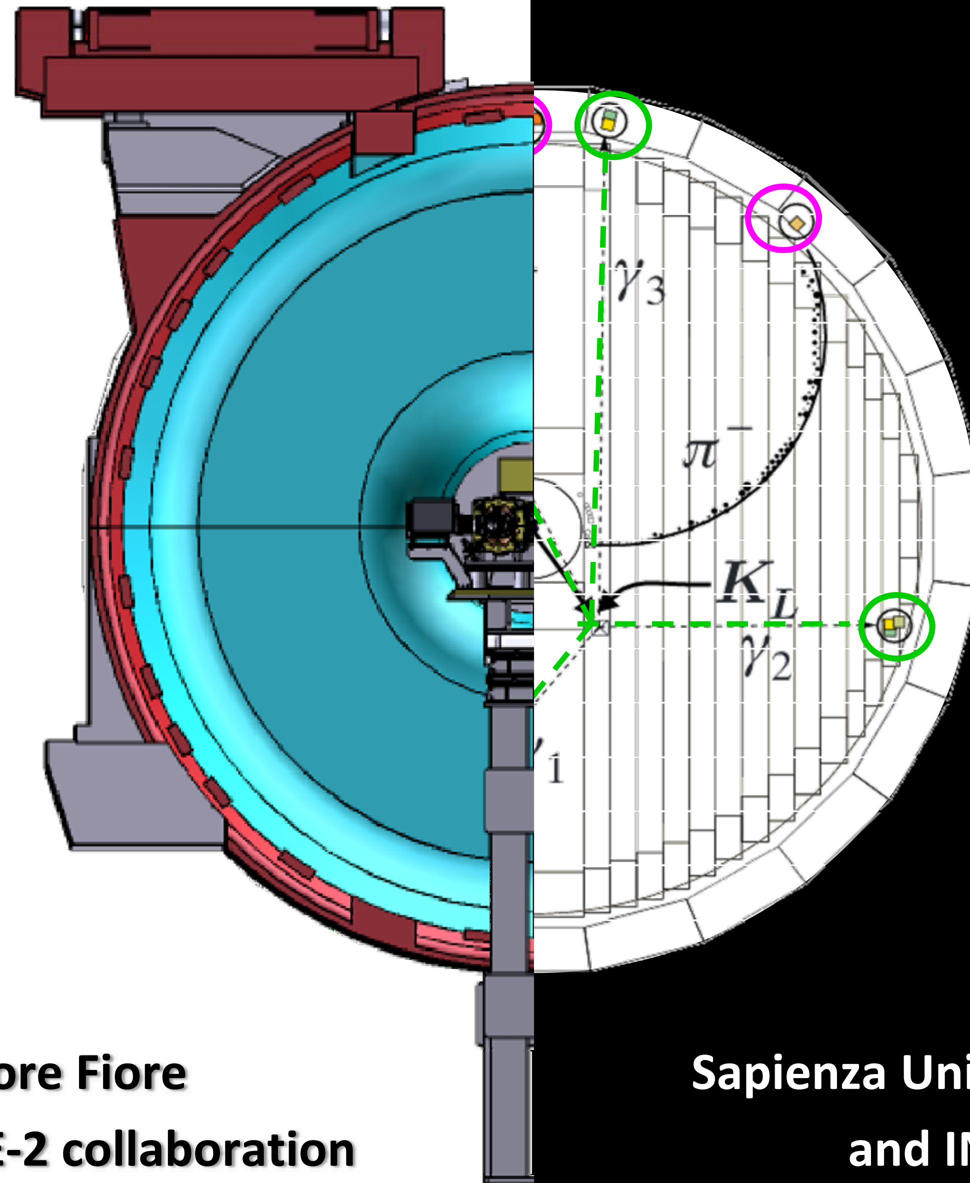
# KLOE-2 project at the DAFNE accelerator upgraded in luminosity





**Salvatore Fiore**

**for the KLOE-2 collaboration**

**Sapienza Universita' di Roma**

**and INFN Roma**

# The KLOE collaboration

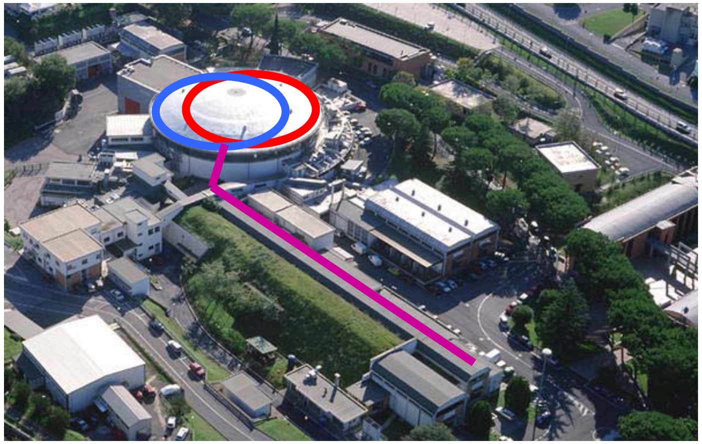
Frascati φ-factory DAφNE:

an $e^+e^-$ collider @ √s =1019.4 MeV = $M_\phi$

Best performances in 2005:

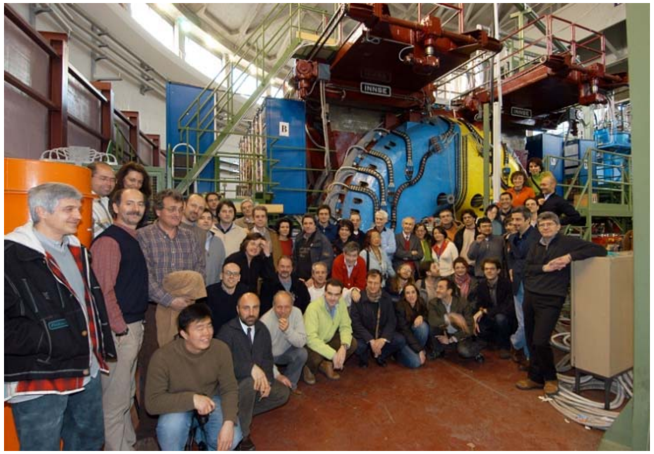
✓ $L_{peak} = 1.4 \times 10^{32}\ cm^{-2}s^{-1}$

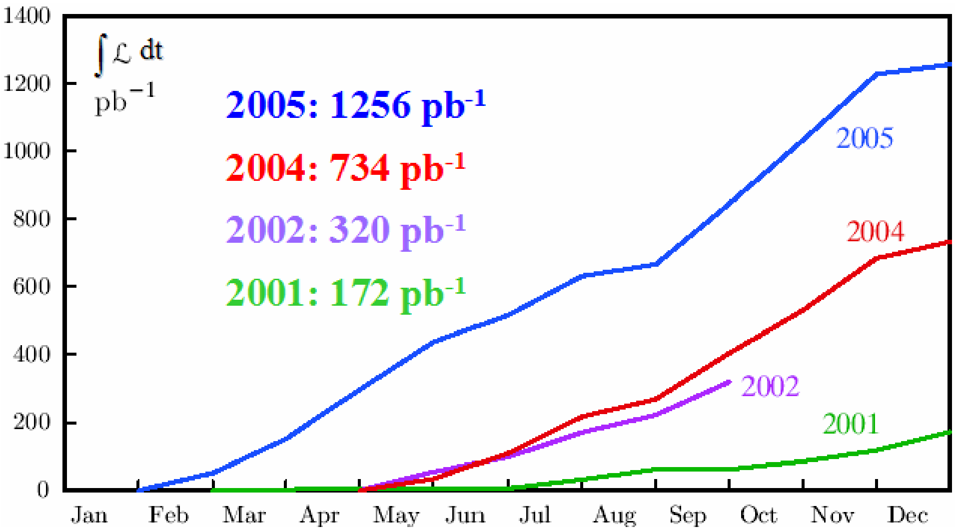
✓ $\int Ldt = 8.5\ pb^{-1}/day$



KLOE has acquired 2.5 $fb^{-1}$ @ √s=$M_\phi$ during years 2001-05

+ 250 $pb^{-1}$ *off-peak* @ √s=1 GeV





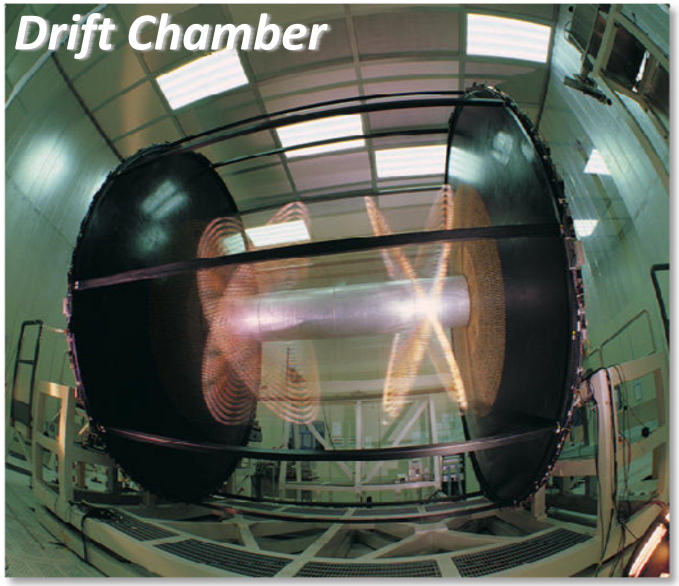

***In these years tenths of articles have been published, with the contribution of more than 100 researchers***

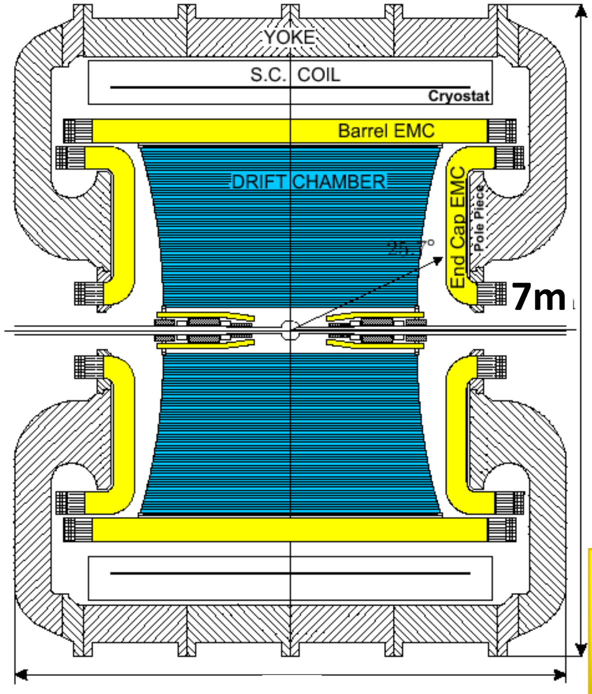
# The KLOE detector

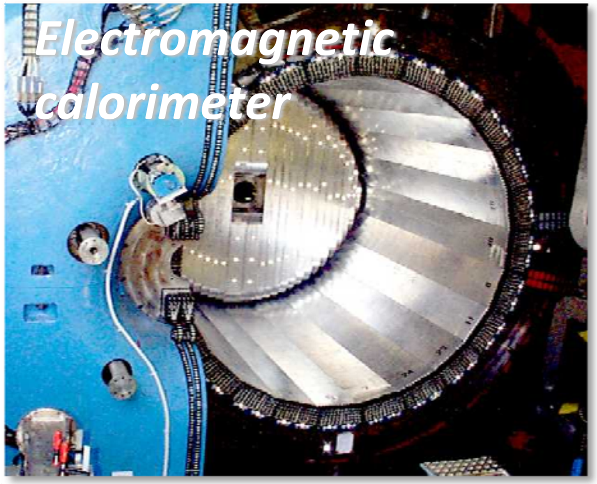
- 4 m diameter × 3.3 m length
- 90% helium, 10% isobutane
- 12582/52140 sense/tot wires
- All-stereo geometry

$\lambda_{KS}$ = 0.6 cm
$\lambda_{KL}$ = 340 cm
$\lambda_{K\pm}$ = 95 cm

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




$\sigma_{r\phi}$ = 150 μm $\sigma_z$ = 2 mm
$\sigma_V$ = 3 mm $\sigma_p/p$ = 0.4 %

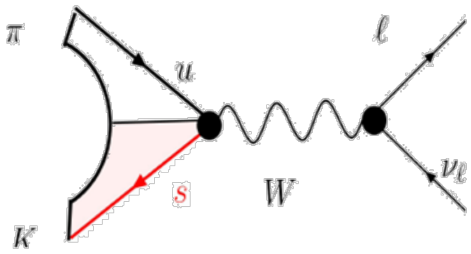
B = 0.52 T

$\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$
$\sigma_t = 54\ ps/\sqrt{E(GeV)}$
$\oplus$ 140 ps(calib)

# *Kaon and light hadron physics at KLOE*

# Kaon Physics for $V_{us}$ and universality

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




$K_{\ell 3}$: $K \rightarrow \pi \ell \nu$

Vector transition: only 2nd order SU(3) breaking [Ademollo-Gatto]

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

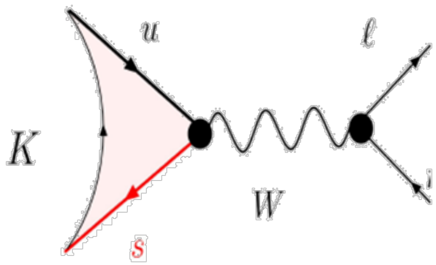
$|V_{ud}|^2 + |V_{us}|^2 = 1 \quad |V_{ub}|^2$ negligible

- ❖ Lepton-Quark universality of weak int.

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

---

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




$K_{\ell 2}$: $K \rightarrow \ell \nu$

Helicity suppressed: enhanced sensitivity to NP

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

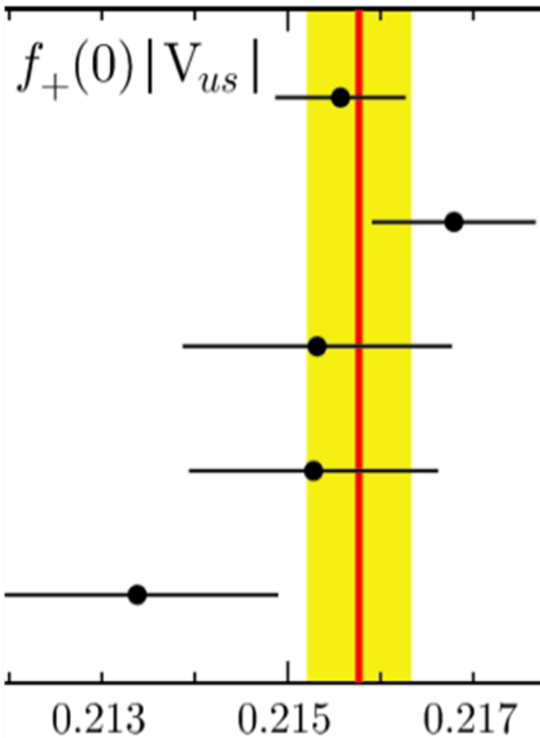
} $\Gamma(K_{\mu 2})/\Gamma(\pi_{\mu 2})$

- ❖ Lepton Flavor Violation test with $\Gamma(K_{e2})/\Gamma(K_{\mu 2})$

***KLOE has measured all relevant Inputs for charged & neutral kaons:***

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

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




| | | err % |
|---|---|---|
| $K_Le3$ | 0.2155(7) | 0.3 |
| $K_L\mu3$ | 0.2167(9) | 0.4 |
| $K_Se3$ | 0.2152(14) | 0.7 |
| $K^{\pm}e3$ | 0.2152(13) | 0.6 |
| $K^{\pm}\mu3$ | 0.2132(15) | 0.7 |

**JHEP04(2008)059**

All KLOE exp. inputs but $K_S$ lifetime 2010 result:
$\tau_S$ = 89.56(03)$_{stat}$ (04)$_{syst}$ ps

**Lepton universality**

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

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

$\tau$ decays: $(r_{\mu e})_\tau$ = 1.0005(41) (PDG06)
$\pi$ decays: $(r_{\mu e})_\pi$ = 1.0042(33)

**KLOE average $|V_{us}|f_+(0)$ = 0.2157(6)** $\chi2$/ndf=7/4 (13%)

World Average 0.2163(5)

**$|V_{us}|$ = 0.2237(13)**
**1- $|V_{ud}|^2$ - $|V_{us}|^2$ = 9(8)x10$^{-4}$**

**$f_+$ (0)=0.964(5)** — **PRL 100 (2008)**
**$|V_{ud}|$ = 0.97418(26)** — **PRC 77 (2008)**

# $|V_{us}|f_+(0)$: present World Averages

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

| | | % err | Approx. contr. to % err from: BR | $\tau$ | $\delta$ | $I_{K\ell}$ |
|---|---|---|---|---|---|---|
| $K_L e3$ | **0.2163(6)** | **0.26** | 0.09 | **0.20** | **0.11** | 0.06 |
| $K_L \mu 3$ | **0.2166(6)** | **0.29** | 0.15 | **0.18** | **0.11** | 0.08 |
| $K_S e3$ | **0.2155(13)** | **0.61** | **0.60** | 0.03 | **0.11** | 0.06 |
| $K^\pm e3$ | **0.2160(11)** | **0.52** | **0.31** | 0.09 | **0.40** | 0.06 |
| $K^\pm \mu 3$ | **0.2158(14)** | **0.63** | **0.47** | 0.08 | **0.39** | 0.08 |

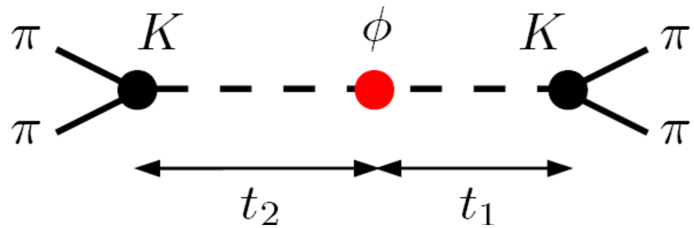
**Experimental Inputs to be improved**

*From Flavianet Kaon WG arXiv:1005.2323v1*

Neutral kaon pairs in a pure quantum state: a unique feature of $\phi$-factory

Study of quantum intereference can probe CPT symmetry and QM at the Planck scale

Sensitivity to interference phenomena for the unique circumstance $\Delta M \sim ½\, \Gamma_s$

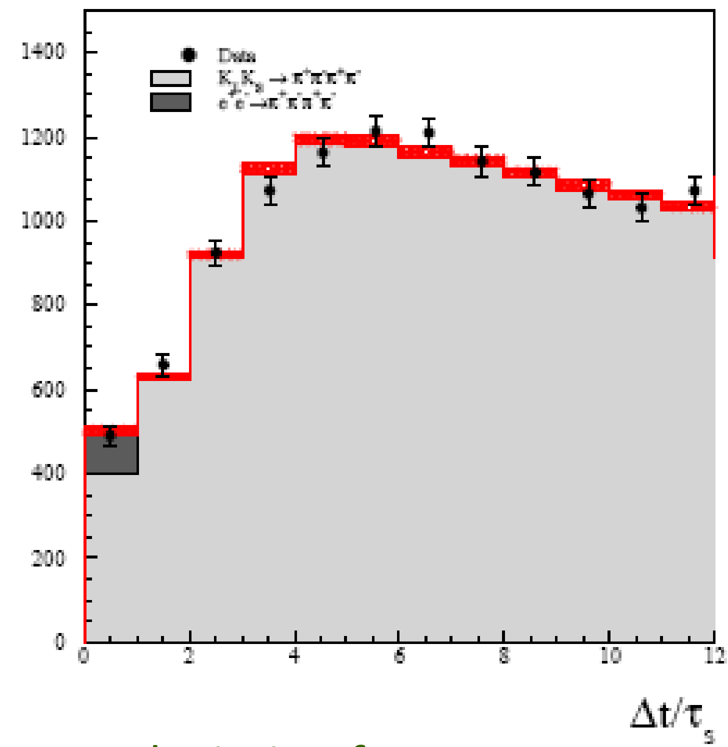



$$\Delta t = |t_1 - t_2|$$

$$I(\pi^+\pi^-, \pi^+\pi^-; \Delta t) \propto$$
$$[e^{-\Gamma_L \Delta t} + e^{-\Gamma_S \Delta t}] +$$
$$-2(1 - \zeta_{SL}) e^{-(\Gamma_S + \Gamma_L)\Delta t/2} \cos(\Delta m \Delta t))$$

$\zeta_{SL} = 0$ Q.M.

$\zeta_{SL} = 0.003 \pm 0.018 \pm 0.006$




This and other decoherence effects should manifest as a deviation from

*$I(\pi^+ \pi^- \pi^+ \pi^-; \Delta t=0)=0$* QM prediction

*We need better vertex resolution for events close to IP to improve sensitivity at $\Delta t=0$*

# Low-energy QCD

## $K_S \to \gamma\gamma$

✓ KLOE can tag $K_S$ by identifying $K_L$ decays, and measure directly the decay

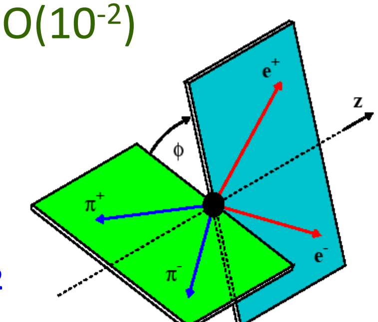
Presently a 3σ discrepancy between KLOE and NA48:

➢ ***Need better rejection from $K_S \to \pi^0\pi^0$ and more data to clarify***

## $\eta \to \pi^+\pi^- e^+ e^-$

η mesons produced by radiative decay $\phi \to \eta\gamma$

A possible non-CKM CP violating mechanism would result in an observable asimmetry $A_\phi$ in the angle between the planes containing the pions and the electrons, $O(10^{-2})$



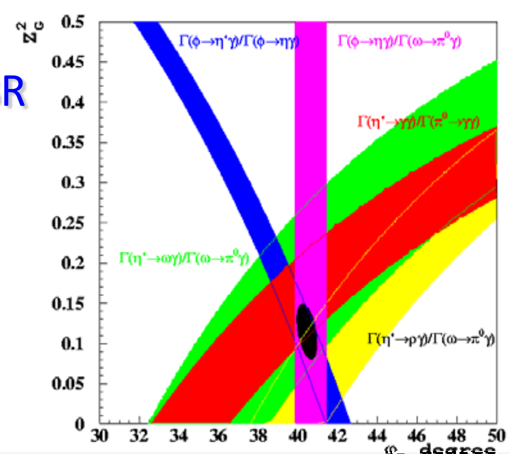

**$A_\phi = -(0.6 \pm 2.5 \pm 1.8) \times 10^{-2}$**
statistical main contrib, $p_{tmin}$=23MeV limits selection efficiency

## η' gluonium content

Using the approach by Bramon et al. KLOE extracts the η' gluonium content $Z_G$ by measuring $R = BR(\phi \to \eta'\gamma)/BR(\phi \to \eta\gamma)$

Gluonium content confirmed at 3σ

More statistics could improve η'BR and sensitivity to gluonium

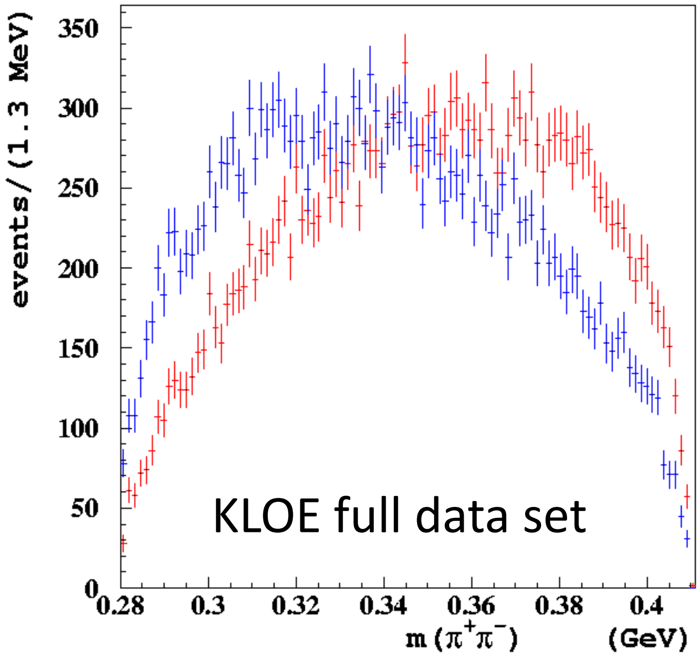


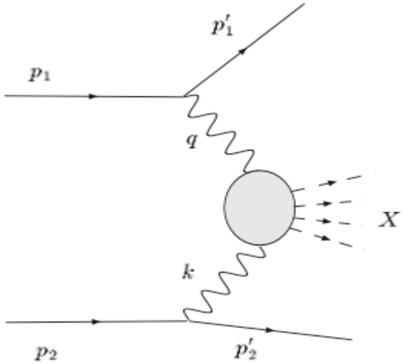
# *Search for $\sigma$ meson*

- In $\phi \to f_0\gamma \to \pi^+\pi^-\gamma$ decay analisys, a contribution from $\sigma$ meson must be accounted for in the $\pi\pi$ invariant mass spectrum
- $\eta' \to \pi\pi\eta$ decay can be mediated by scalar mesons including $\sigma$ ; studied at KLOE with early data
- golden channel is $\pi^+\pi^-\eta$ final state, with $\eta \to \gamma\gamma$

Expected $M_{\pi\pi}$ shape using Faribortz-Schechter model, including analysis efficiency (flat in $M_{\pi\pi}$ shape).

Reconstruction effects not included **Blue: without $\sigma$(600)** **Red: $\sigma$(600) included**






"$\gamma\gamma$ physics" stands for $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^- + X$

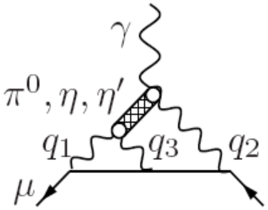
$J^{PC} = 0^{\pm+}, 2^{\pm+}$ final states through quasi-real photons: $\pi\pi(\sigma), \eta, \eta'$, $f_0$, $a_0$

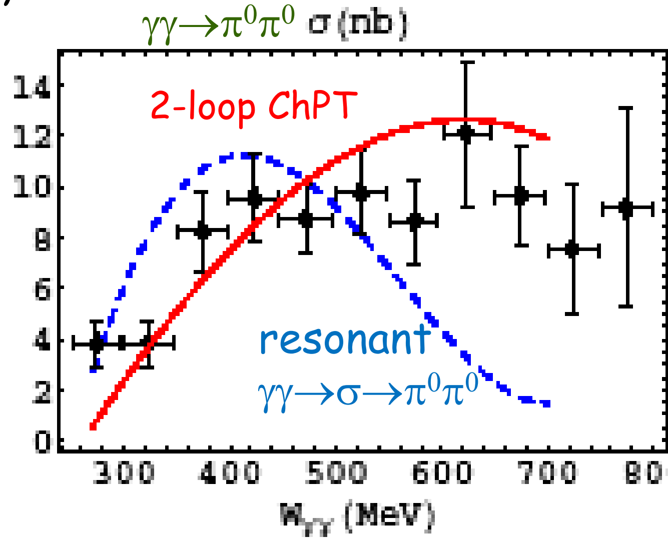
For $W_{\gamma\gamma}$<1GeV, present experimental situation is unsatisfactory:

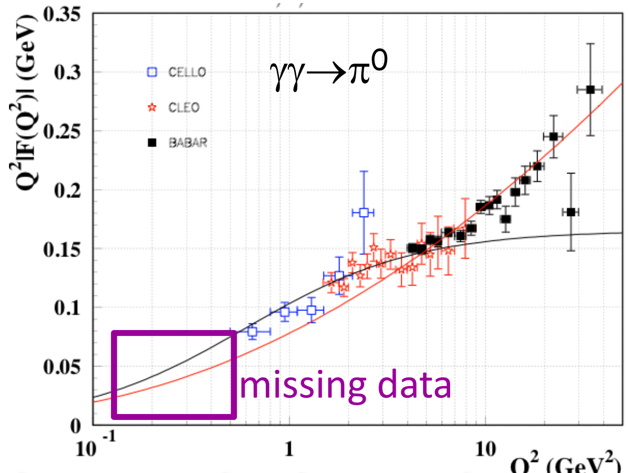
- small data samples and large backgrounds
- small detection efficiencies and particle ID for low-mass hadronic states

✓ Study of $\gamma\gamma\to\pi^0\pi^0$ could tell about the existence and nature of $\sigma$ meson

✓ meson transition form factors through $\gamma\gamma\to\pi^0$, $\eta$ decays : low momentum transfer form factor crucial for light-by-light contribution to g-2




*$\gamma\gamma$ events acquired at the $\phi$ peak would suffer from $\phi$ decays as background:*

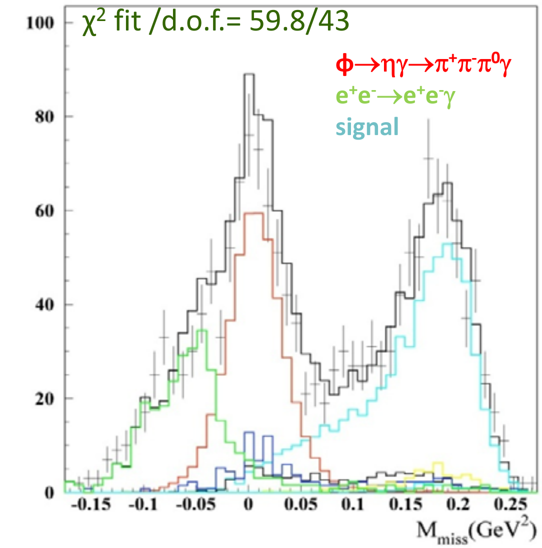
✓ *use KLOE off-peak data @ 1GeV*

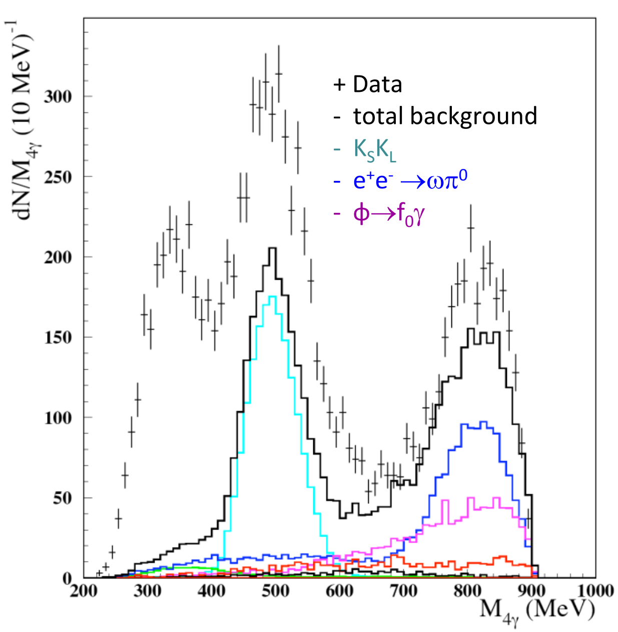
## $\gamma\gamma \to \eta$

- Data sample: 240 pb-1 @ √s = 1 GeV
- Selected channel: $\eta \to \pi^+\pi^-\pi^0$ ; main background: $\phi \to \eta\gamma$ with undetected photon

➢ Extraction of $\sigma(e^+e^- \to e^+e^-\eta)$ and $\Gamma_{\gamma\gamma}$ in progress

➢ Statistical accuracy on $\Gamma_{\gamma\gamma}$ comparable with existing measurements




## $\gamma\gamma \to \sigma \to \pi^0\pi^0$

- Cleanest channel to assess existence and nature of the σ meson
- $\pi^0\pi^0$ preferred w.r.t. $\pi^+\pi^-$ due to smaller background contamination
- 240 pb-1 @ √s = 1 GeV

➢ Excess of ~4000 events w.r.t. known backgrounds in the $\gamma\gamma \to \sigma(600) \to \pi^0\pi^0$ region

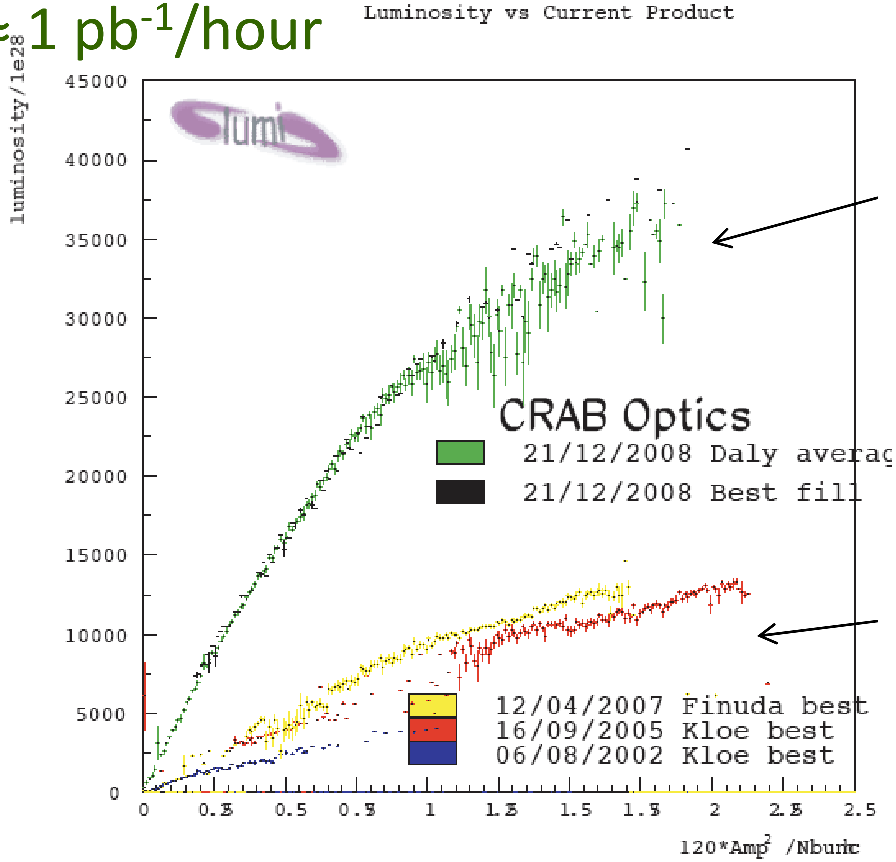
➢ Background subtraction and study of differential cross-section in progress

## *From KLOE to KLOE-2*

# New DAΦNE collider

New interaction scheme implemented:

- ✓ large beam crossing angle + crabbed waist sextupoles
- ✓ Luminosity increase factor ~ 3
- ✓ ∫ Ldt ≈ 1 pb$^{-1}$/hour




Max L=4.5x $10^{32}$ cm$^{-2}$s$^{-1}$
SIDDHARTA
Run (2008/09)

KLOE run
(2002/05)

***We already have now a deeply renewed machine capable of delivering ~5 fb$^{-1}$/yr***

# The KLOE-2 project schedule

KLOE-2 project consists of two phases:

1. ***STEP-0 phase***, in which we:
   - upgraded the detector with ***two lepton-tagging systems for $\gamma\gamma$-physics*** and
   - will run for about one year to collect an integrated luminosity of ***5 $fb^{-1}$***

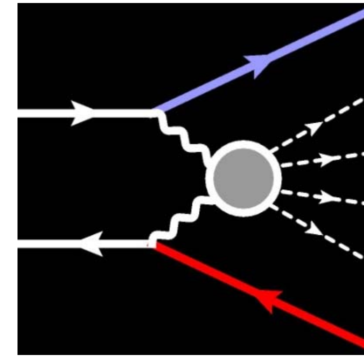
2. ***STEP-1 phase***, in which we:
   - wil upgrade the detector with ***a new Inner Tracking system (IT), a new Quadrupole CALorimeter (QCALT) and Crystal CALorimeter covering low polar angles (CCALT)*** and
   - will run to collect an integrated luminosity of ***20 $fb^{-1}$***

*Tagging $\gamma\gamma$ events by detecting $e^+e^-$ is mandatory to reduce backgrounds*

*Two lepton-tagging systems for $\gamma\gamma$-physics have been installed last year:*

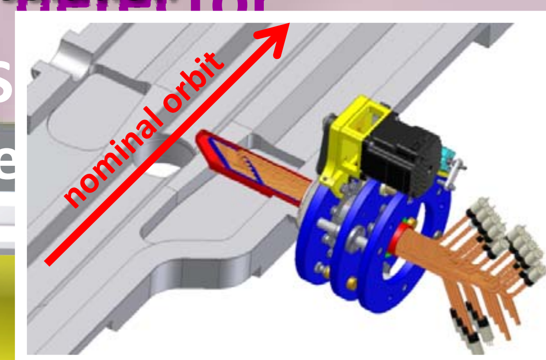
**LET & HET**

✓ LYSO+SiPMs & Scint+PMTs



## HET: E>400MeV, 11m from IP

**2 scintillator hodoscopes inserted in Daϕne beam pipe: 2.5 MeV resolution**




**mechanics is ready, detector is ready and electronics is in commissioning phase**

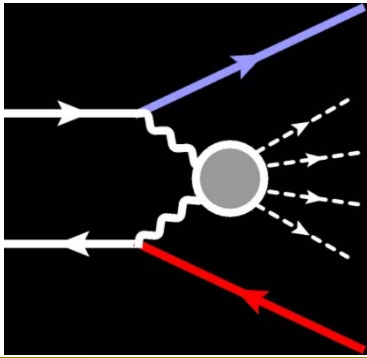
**plan to install HET next April**

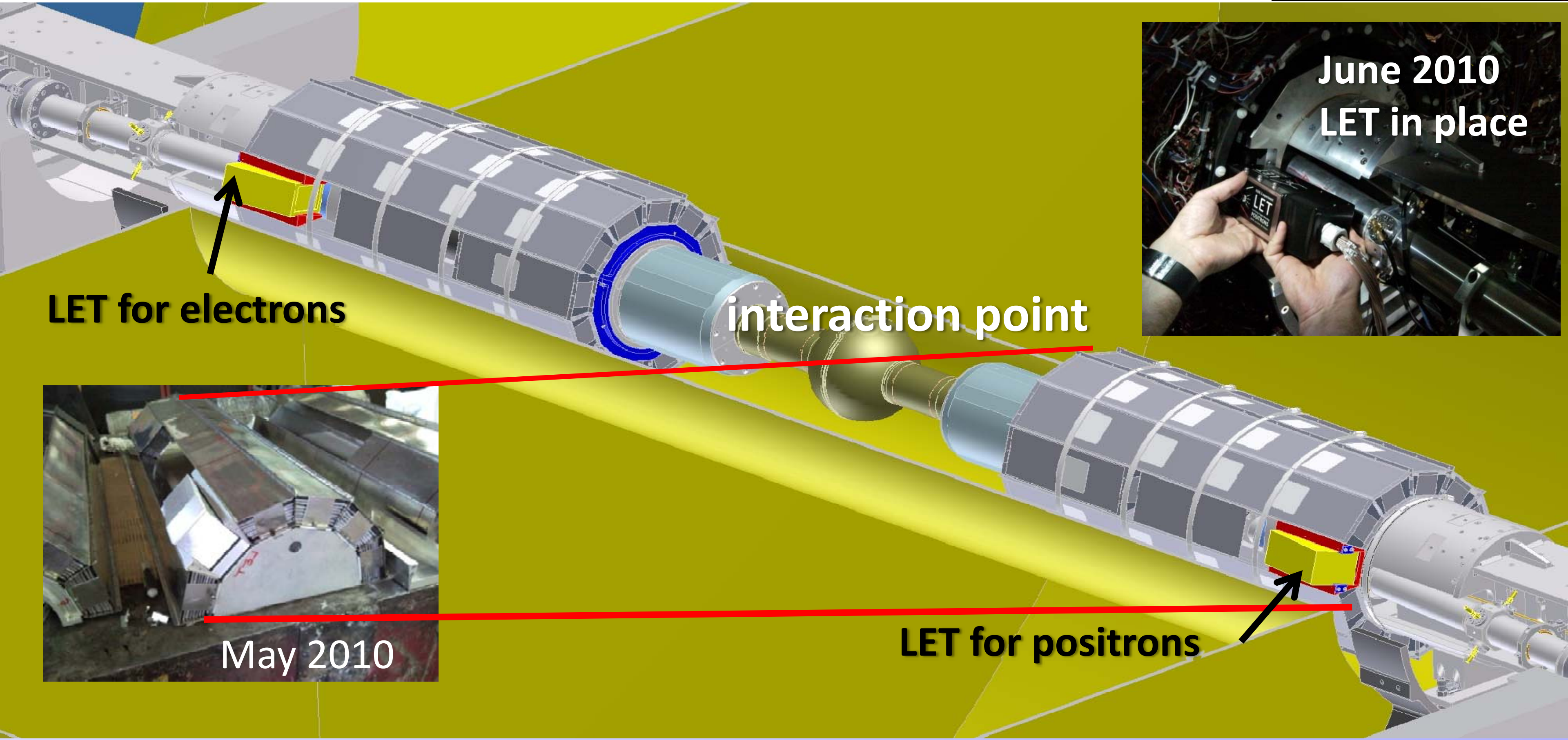
# *Present detector upgrades*

***Tagging $\gamma\gamma$ events by detecting $e^+e^-$ is mandatory to reduce backgrounds***

*Two lepton-tagging systems for $\gamma\gamma$-physics have been installed last year:*
**LET & HET**

✓ LYSO+SiPMs & Scint+PMTs





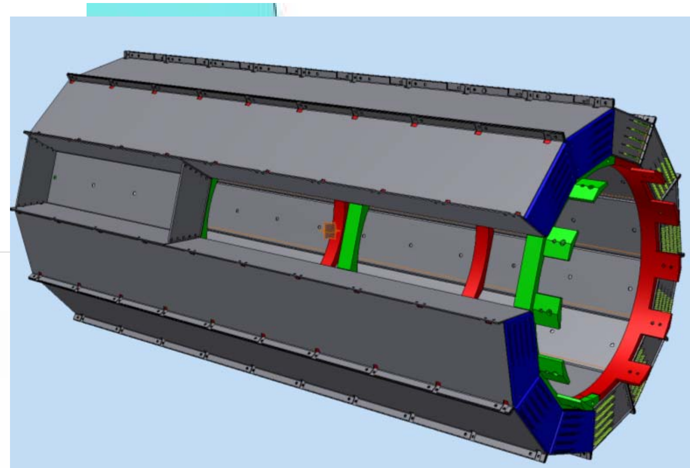
# *Forthcoming detector upgrades*

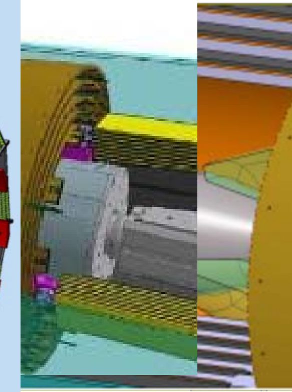
During 2012 new sub-detectors will be added inside KLOE in order to improve its performance:

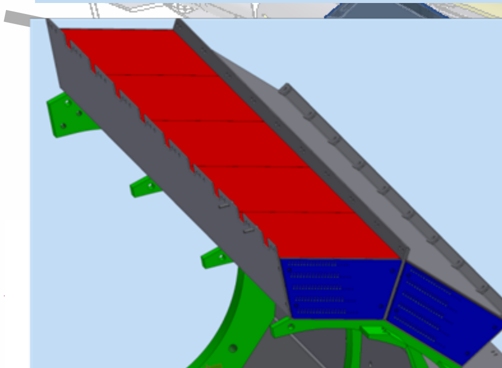
CCAL
- ✓ LYSO + SiPM
- ✓ Veto for $\gamma$'s from IP ($21° \rightarrow 10°$ acceptance)

INNER TRACKER
- ✓ 4 layers of cylindrical triple GEM
- ✓ Better vertex reconstruction near IP
- ✓ Larger acceptance for low pt tracks

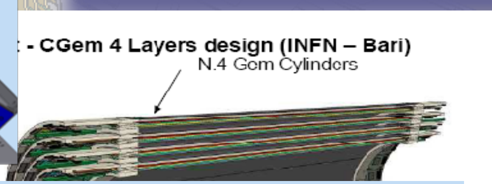
QCALT
- ✓ W + scintillator tiles + SiPM/WLS
- ✓ quadrupoles coverage for $K_L \rightarrow \pi^0\pi^0\pi^0$ decays ($\gamma$ towards quads.)

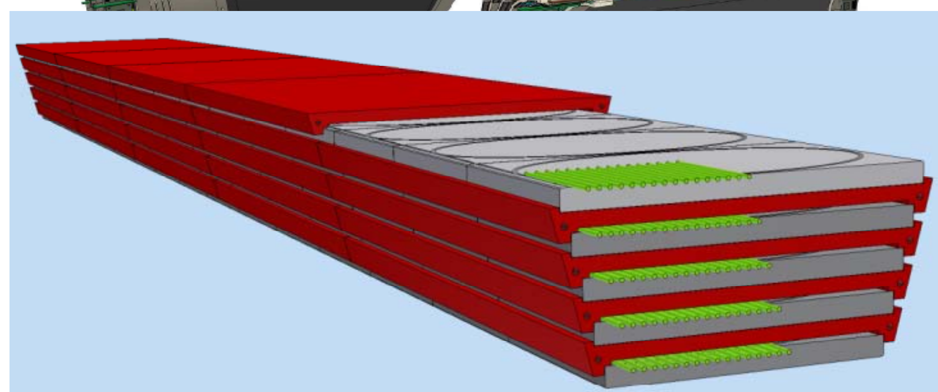






Dodecagonal structure of CCALT



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

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$\Delta BR(K_S e3)/BR(K_S e3)$: 0.6% with +5fb$^{-1}$ KLOE-2/step-0

0.3% with 25fb$^{-1}$ and Inner Tracker better tracking performance for decays close to IP in terms of acceptance and background rejection

$\Delta\tau_L/\tau_L$: 0.27% adding 5 fb$^{-1}$ from KLOE-2/step-0

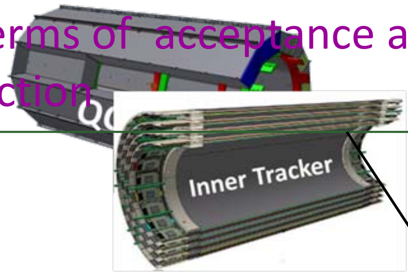
$\Delta\tau_S/\tau_S$: 0.03% is expected adding 5 fb$^{-1}$ from KLOE-2/step-0 .

< 0.2%: inserting QCALT improving photon reconstruction & control of the systematics

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

$\Delta\tau_\pm/\tau_\pm$: 0.1% is expected with KLOE + 5 fb$^{-1}$ KLOE-2 /step-0

x2 inserting Inner Tracker, allowing detection of K$^\pm$ tracks closer to the IP, improves accuracy of the decay length technique





| | | % err | Approx. contr. to % err from: BR | τ | δ | $I_{K\ell}$ |
|---|---|---|---|---|---|---|
| $K_L e3$ | 0.2163(6) | 0.26 | 0.09 | 0.20 | 0.11 | 0.06 |
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| $K^\pm \mu 3$ | 0.2158(14) | 0.63 | 0.47 | 0.08 | 0.39 | 0.08 |

# $|V_{us}|f_+(0)$: future perspectives with KLOE-2/step0

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

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

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

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

| | | % err | Approx. contr. to % err from: BR | $\tau$ | $\delta$ | $I_{K\ell}$ |
|---|---|---|---|---|---|---|
| $K_L e3$ | **0.2155(4)** | **0.21** | 0.09 | **0.13** | **0.11** | 0.09 |
| $K_L\mu3$ | **0.2167(5)** | **0.25** | 0.10 | **0.13** | **0.11** | 0.15 |
| $K_S e3$ | **0.2153(7)** | **0.33** | **0.30** | 0.03 | **0.11** | 0.09 |
| $K^\pm e3$ | **0.2152(8)** | **0.37** | **0.25** | 0.05 | **0.25** | 0.09 |
| $K^\pm\mu3$ | **0.2132(9)** | **0.40** | **0.27** | 0.05 | **0.25** | 0.15 |

World-average uncertainties for BR($K_L e3$) , $\delta$ and $I_{K\ell}$ from **updated Flavianet paper *arXiv:1005.2323v1***

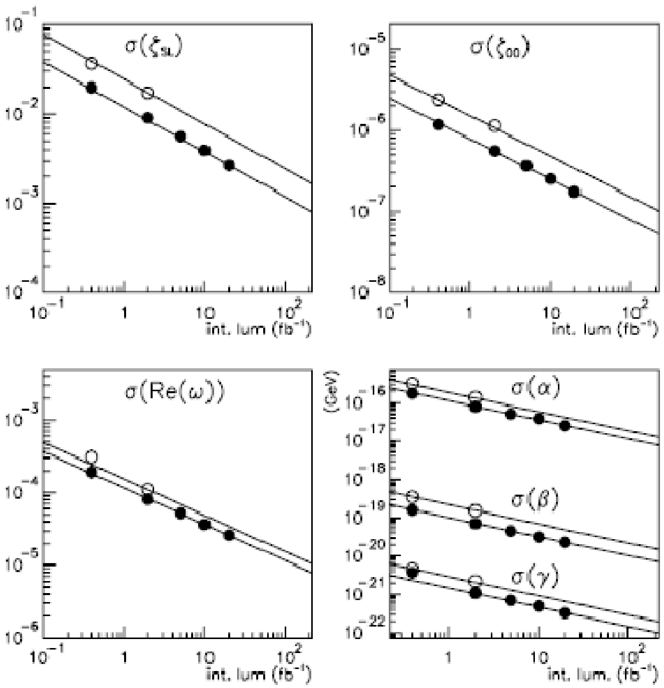
# Kaon Interferometry

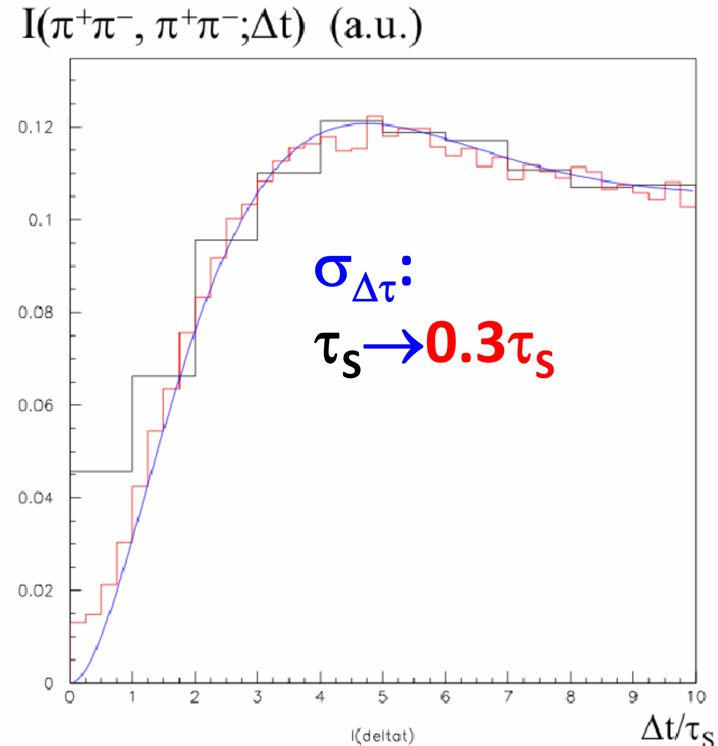
Neutral kaon pairs in a pure qu… … ature of ϕ-factory

Study of quantum intereferen… …ry and QM at the Planck scale

Sensitivity to interference phe… …rcumstance $\Delta M \sim \frac{1}{2}\Gamma_S$


+20fb$^{-1}$




This and other decoherence effects should manifest as a deviation from $I(\pi^+\pi^-, \pi^+\pi^-; \Delta t=0)=0$ QM prediction

**Sensitivity to decoherence parameters with KLOE (open circles) and upgraded KLOE-2 (full circles)**

*We need better vertex resolution for events close to IP to improve sensitivity at $\Delta t=0$*

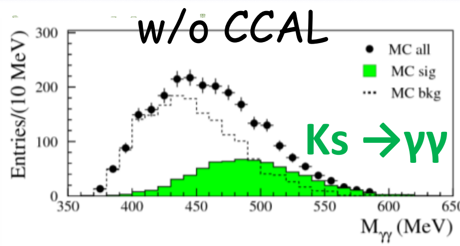
# Low-energy QCD

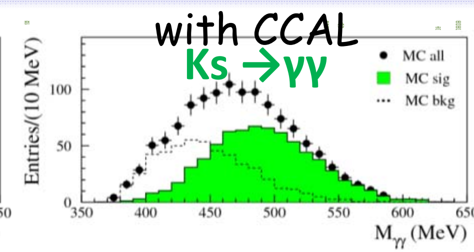
## $K_S \to \gamma\gamma$

✓ … ca…g $K_S$ by identify… … the


**+20fb$^{-1}$**

Pre…ntly a 3σ discrepancy be…




➢ Ne… **Improved rejection from $K_S \to \pi^0\pi^0$ and larger data sample**

## $\eta \to \pi^+\pi^- e^+ e^-$

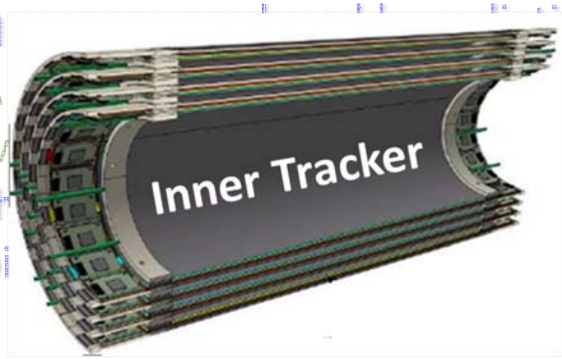
η … …ive decay $\phi \to \eta\gamma$

A … …ting mechanism

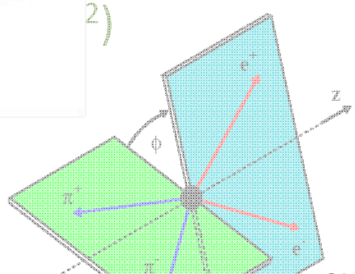
w… …asimmetry $A_\phi$ in

th… …s containing the

pi… …2)




**+20fb$^{-1}$**



$A_\phi = (0.6 \pm 2.5 \pm 1.8) \times 10^{-2}$ statistical main contrib, $p_{tmin}$=23MeV limits selection

**IT: $p_{tmin}$:23MeV → 16MeV; +20fb$^{-1}$**
**→ 0.8-1% precision on $A_\phi$**

## η′ gluonium content

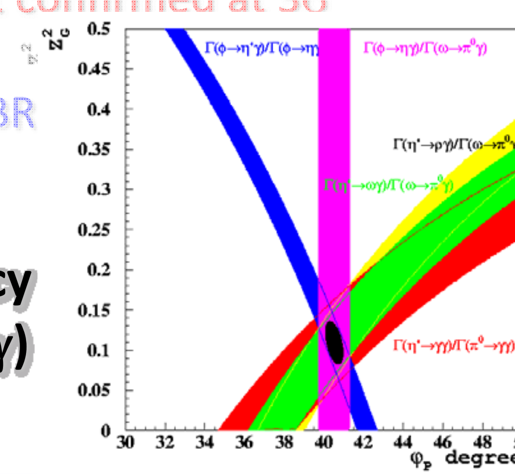
Using the approach by Bramon et al. KLOE extracts the η′ … content $Z_G$ by measuring R= BR(φ→η′γ)/BR(φ→ηγ)

**+5fb$^{-1}$**

Gluonium content confirmed at 3σ

More statistics could improbe η′BR and sensitivity to gluonium

**Frac. accuracy on BR(η′→γγ) 2%→1%**



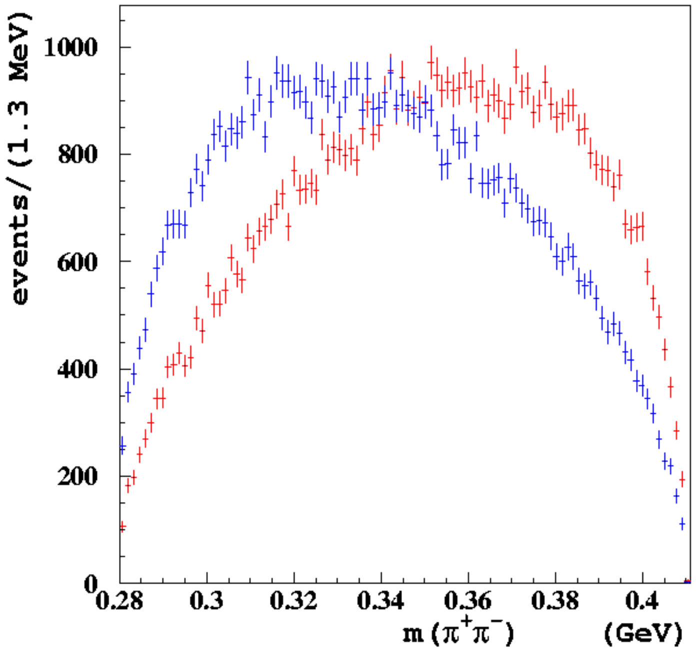
# Search for σ meson

- In $\phi \to f_0\gamma \to \pi^+\pi^-\gamma$ deacy analisys, a contribution from σ meson must be accounted for in the ππ invariant mass spectrum
- $\eta' \to \pi\pi\eta$ decay can be mediated by scalar mesons including σ ; studied at KLOE with early data
- golden channel is $\pi^+\pi^-\eta$ final state, with $\eta \to \gamma\gamma$

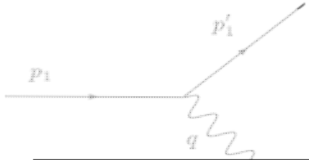
Expected $M_{\pi\pi}$ shape using Faribortz-Schechter model, including analysis efficiency (flat in $M_{\pi\pi}$ shape).

Reconstruction effects not included **Blue: without σ(600)** **Red: σ(600) included**

***+5fb$^{-1}$***

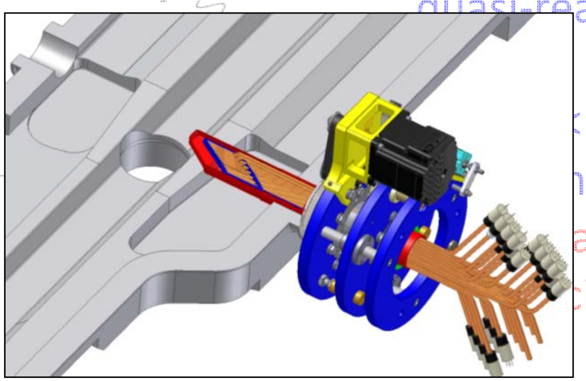


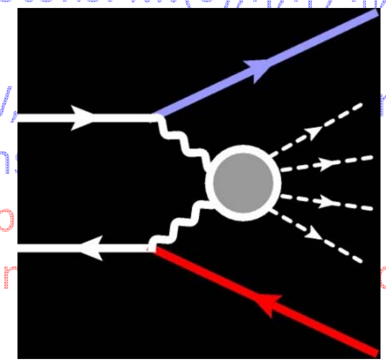
# $\gamma\gamma$ physics with KLOE-2

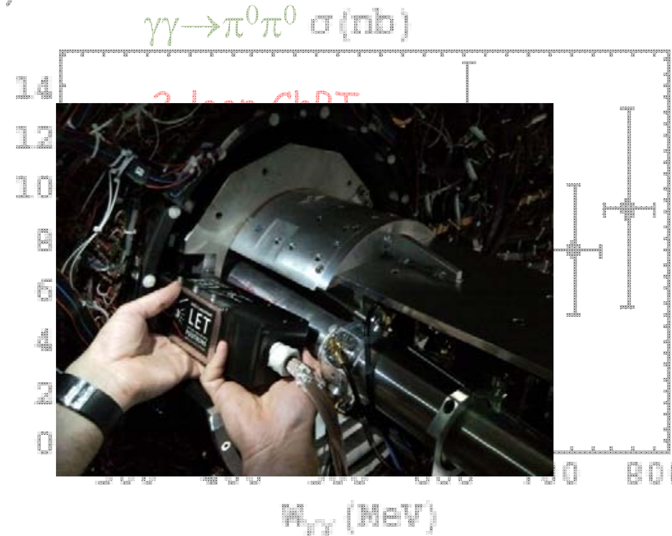


"γγ physics" stands for $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^- + X$

$J^{PC} = 0^{\pm+}, 2^{\pm+}$ final states through quasi-real photons: $\pi\pi(\sigma), \eta, \eta', f_0, a_0$








- ✓ Study of $\gamma\gamma \to \pi^0\pi^0$ could tell about the existence and nature of σ meson
- ✓ meson transition form factors through $\gamma\gamma \to \pi^0$, η decays : low mo... er form factor crucial for light-by-light contribution to g-2 ( in $\gamma\gamma \to$P


## $\gamma\gamma$ taggers

- ➢ **acquire $\gamma\gamma$ events at the ϕ-meson peak suppressing the background coming from Kaon decays**
- ➢ **increase statistics for $\gamma\gamma$ analisys up to 500 pb$^{-1}$ during Step-0**

*γγ events acquired at the ϕ peak would suffer from ϕ decays as background:*

- ✓ *use KLOE off-peak data @ 1GeV*

# Detector status: ready to take data

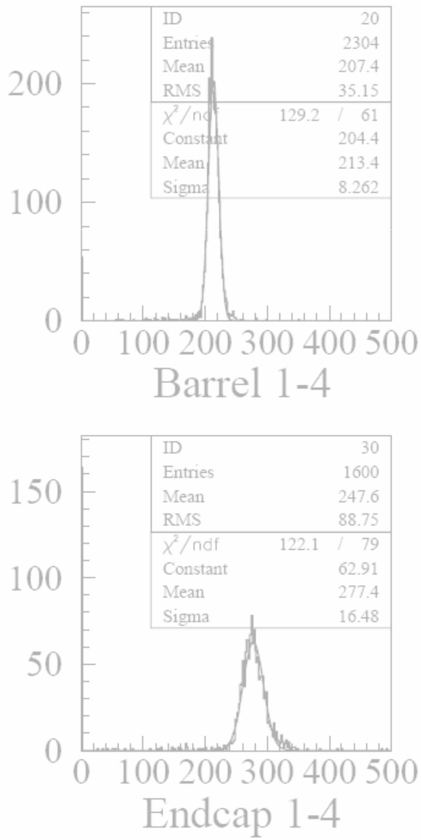
July 2010
B-field ON
First set of DC & EMC calibration

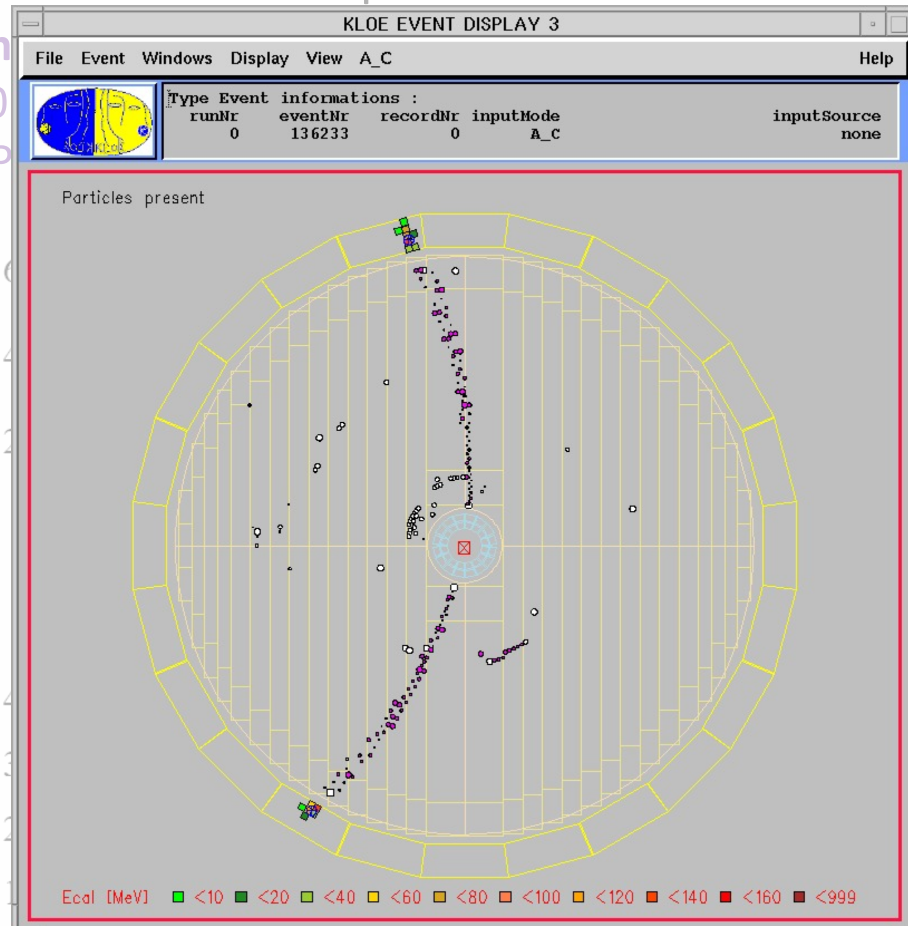
December 2010
Refined DC & EMC calibration
First operation with DAFNE On

March 2011
Collisions from DAFNE

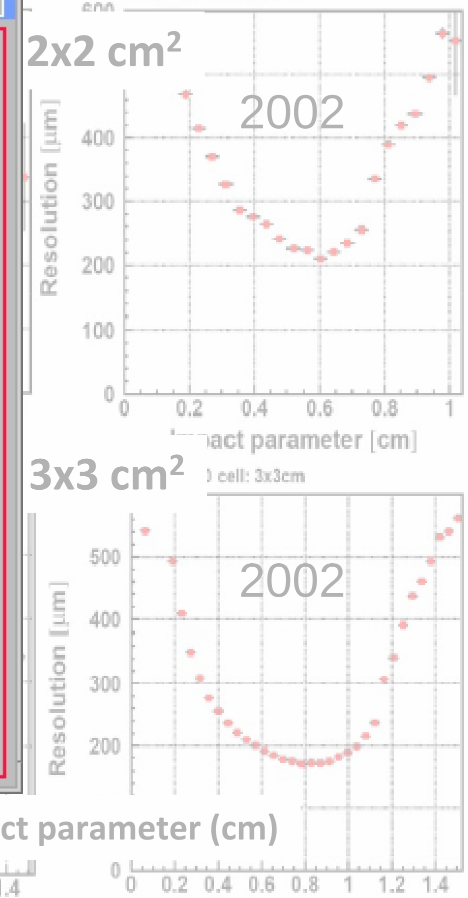
**Electromagnetic Calorim**
- Time calibration: 10-20
- Charge calibration: MIP

.5 ns precision







# Conclusions

KLOE collaboration achieved several precision Kaon and Hadron Physics results

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

- **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 χPT (KS decays)
- **Spectroscopy of light mesons**
  - η, η', $f_0$ , $a_0$, σ in ϕ radiative decays
- **γγ physics**
  - Study of Γ(S/PS→γγ), test of χPT, existence and properties of σ(600) meson, PS Transition Form Factor
- **Dark Matter searches (light bosons at O(1 GeV))**

***References : KLOE-2 Collaboration, Eur. Phys. J C 68 (2010) 619-681***