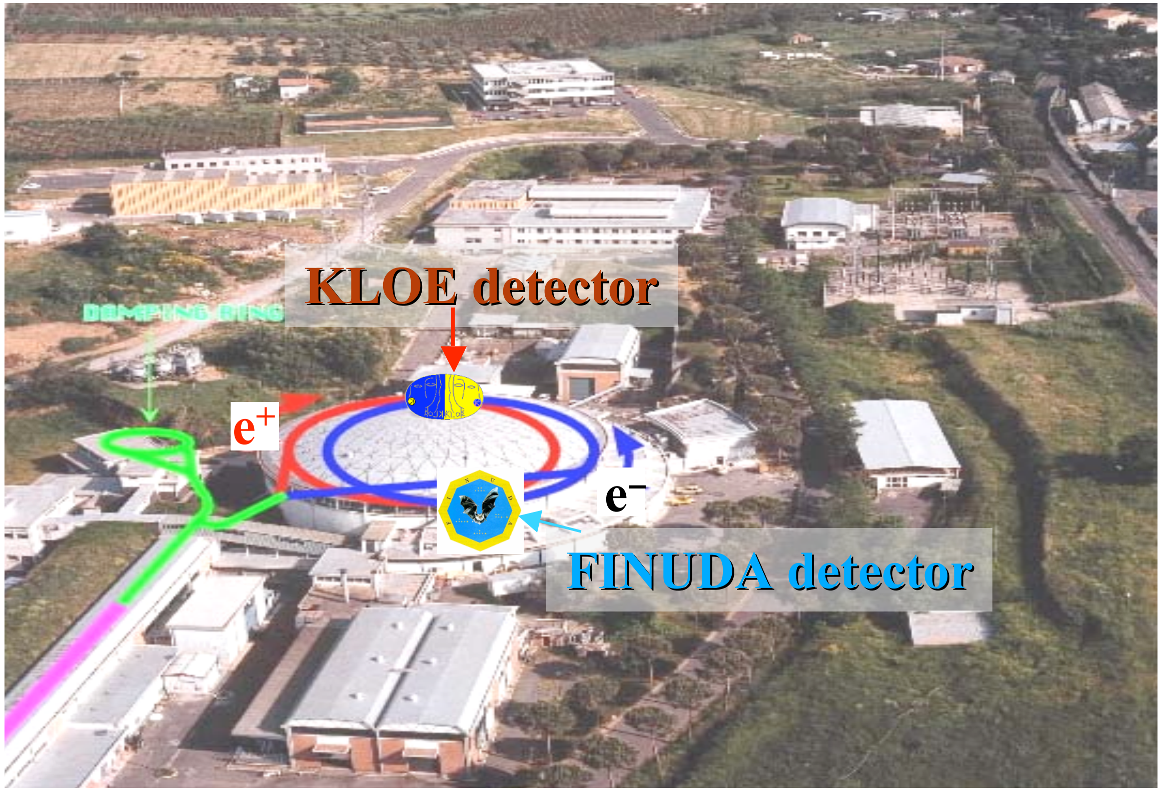
Status of KLOE-2

G. Venanzoni
INFN/FRASCATI

International Workshop on e+e- collisions from Phi to Psi
"PHIPSI09", 13-16 October 2009,
Beijing, China

DAΦNE e^+e^- machine at Frascati (Rome)

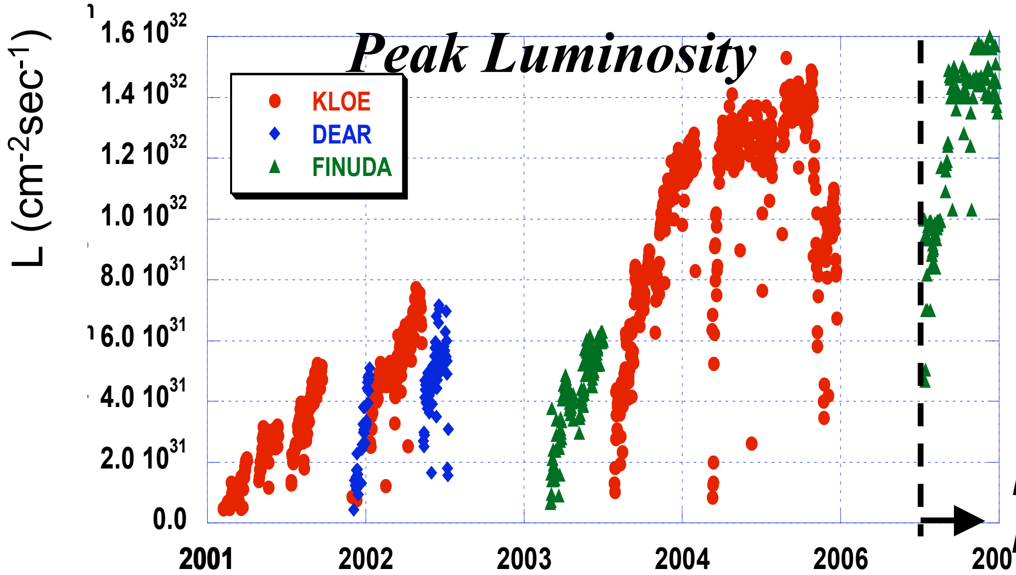


Energy [GeV]	0.51
Trajectory length [m]	97.69
RF frequency [MHz]	368.26
Harmonic number	120
Damping time, τ_E/τ_x [ms]	17.8/36.0
Bunch length at 0 current [cm]	1.0
Bunch length at full current [cm]	2.5
Beam currents e-/e+ [Amps]	1.7/1.3
Number of colliding bunches	107
Beta functions β_x/β_y [m]	1.6/0.017
Emittance, ε_x [mm·mrad] (KLOE)	0.34
Emittance ratio at 0 current [%]	0.25
Emittance ratio at full current [%]	0.60
e- Tunes Qx/Qy	0.091/0.1660
e+ Tunes Qx/Qy	0.1090/0.1910

- $e^+e^- \rightarrow \phi \quad \sqrt{s} \sim m_\phi = 1019.4$ MeV
- beams cross at an angle of 12.5 mrad
- LAB momentum $p_\phi \sim 13$ MeV/c

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

DAΦNE Luminosity history



← $1.6 \times 10^{32}\ cm^{-2}sec^{-1}$

On March 2006 KLOE finished the data taking.
From Apr 2006 to Jun 07 run for FINUDA (~ 1 fb^{-1} taken)

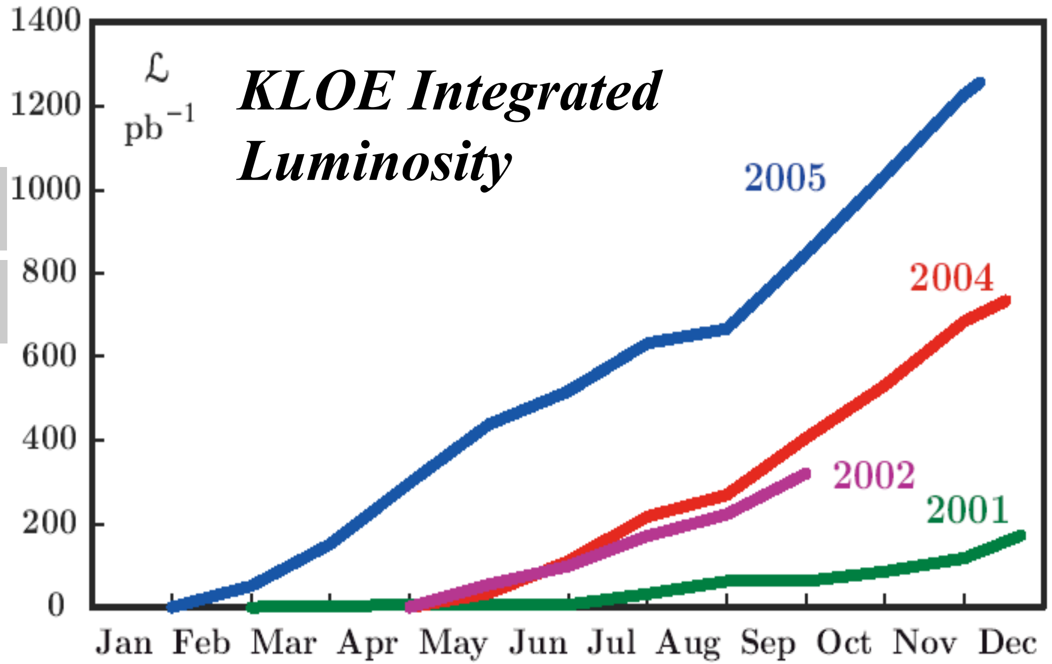
Finuda run

KLOE RUN:

Day performance: 7-8 pb^{-1}

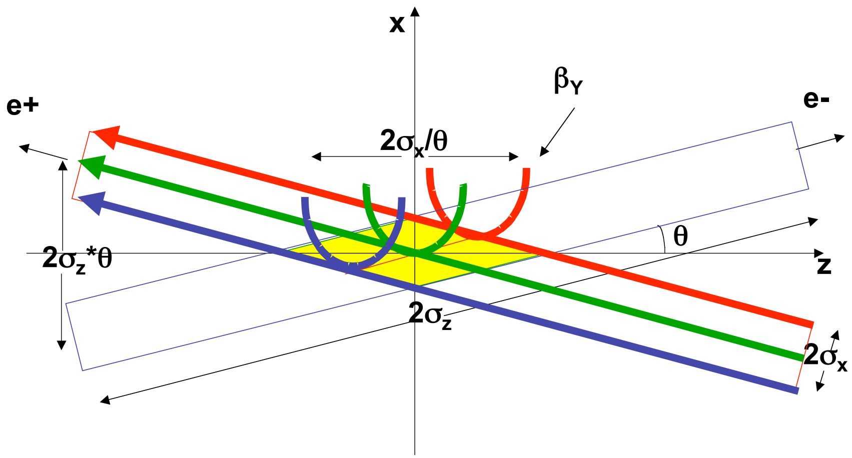
Best month ∫L dt ~ 200 pb^{-1}

Total KLOE ∫L dt ~ 2.4 fb^{-1} on peak (2001,02,04,05) + 250 pb^{-1} at 1 GeV (2006)

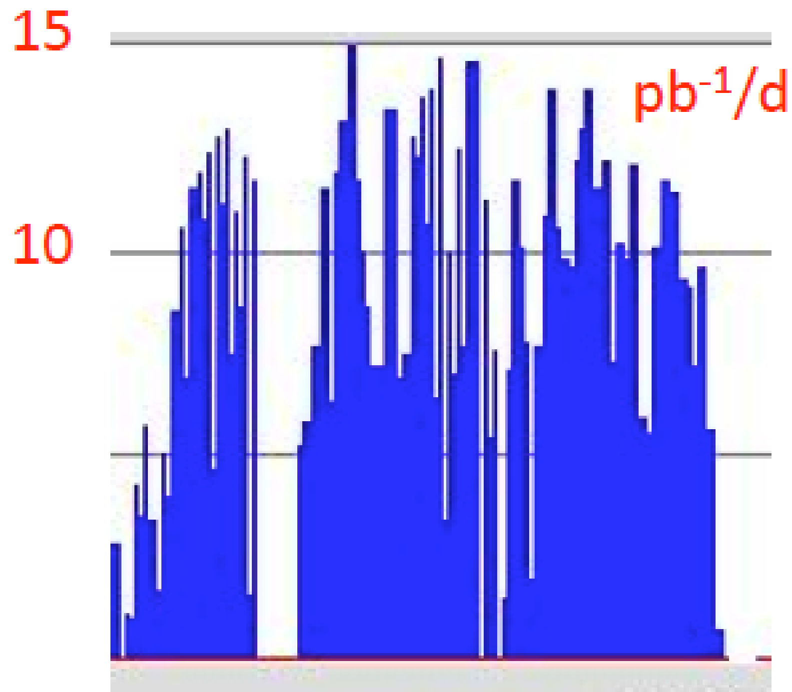


DAΦNE new interaction scheme

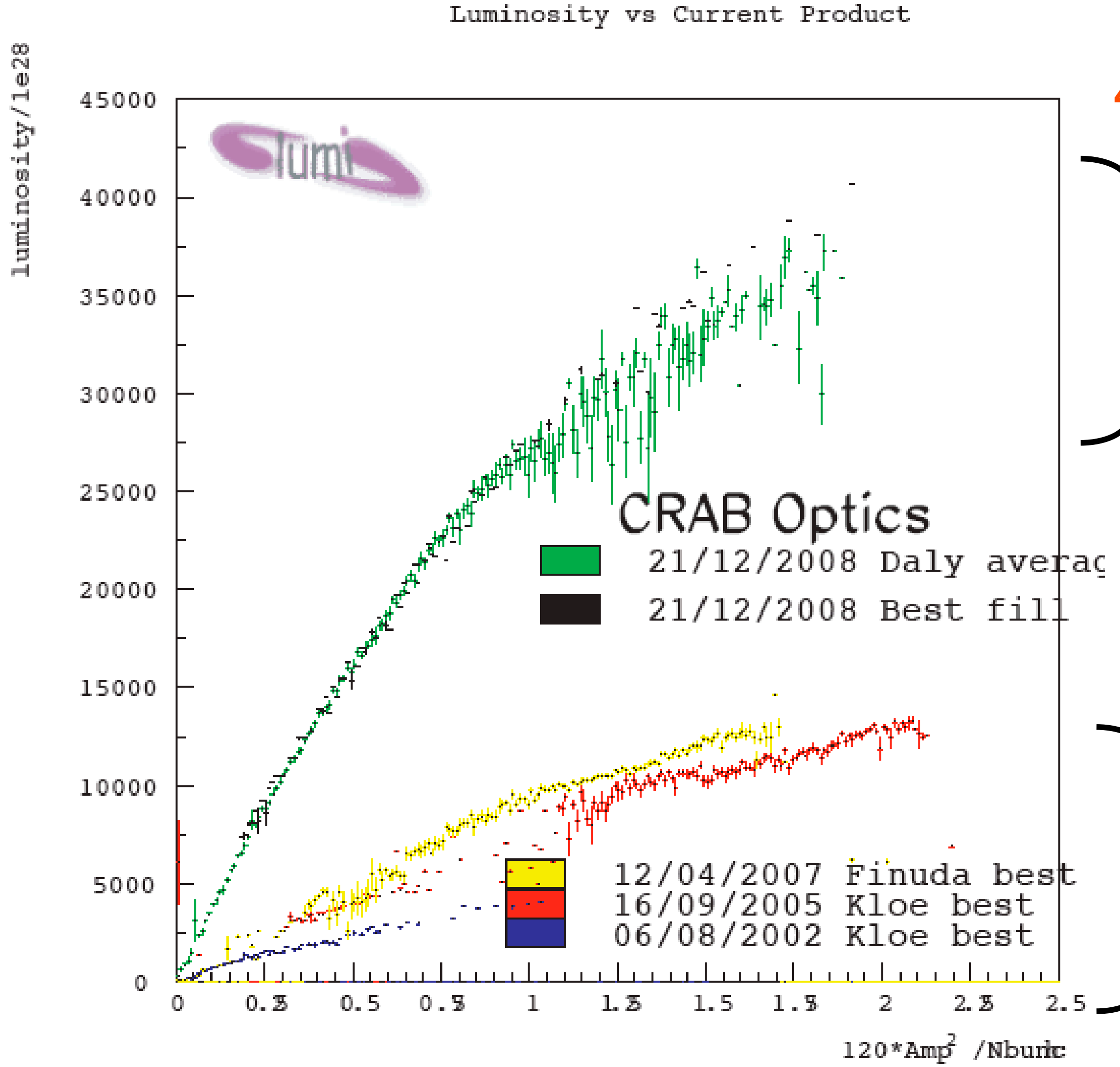
Since the beginning of 2008, DAΦNE has implemented a new interaction scheme based on the use of a large Piwinski angle in combination with a crabbed waist induced by properly designed sextupoles



Results obtained during the run of SIDDHARTA were very good: an increase of a peak luminosity by **~3** and of the integrated luminosity by **~2**



DAΦNE luminosity: new vs old



$4.5 \times 10^{32}\ cm^{-2}s^{-1}$

SIDDHARTA run (2008/09)

KLOE run (2002/05)

A Clear improvement!

KLOE-2 at upgraded Dafne

- We have now a ‘new’ machine capable of delivering ~ 4 fb^{-1}/yr, even accounting for a reasonable duty cycle

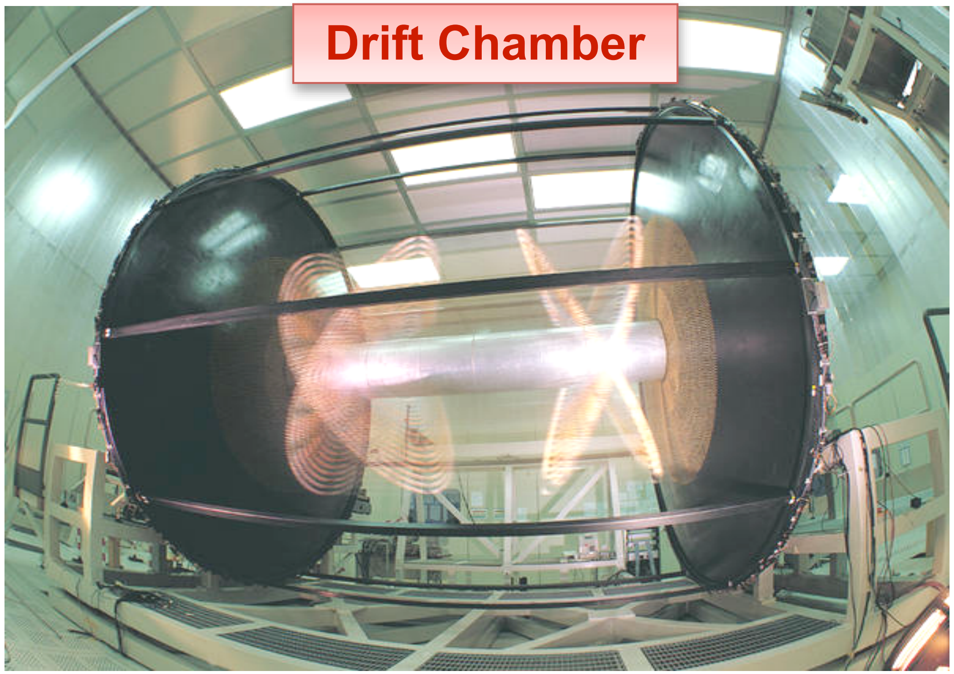
- There is still space for improvements, both in terms of increasing the currents and in terms of operation efficiency

The goal of having the present KLOE statistics increased by ~ an order of magnitude (20-40 fb^{-1}) in the next years is therefore realistic

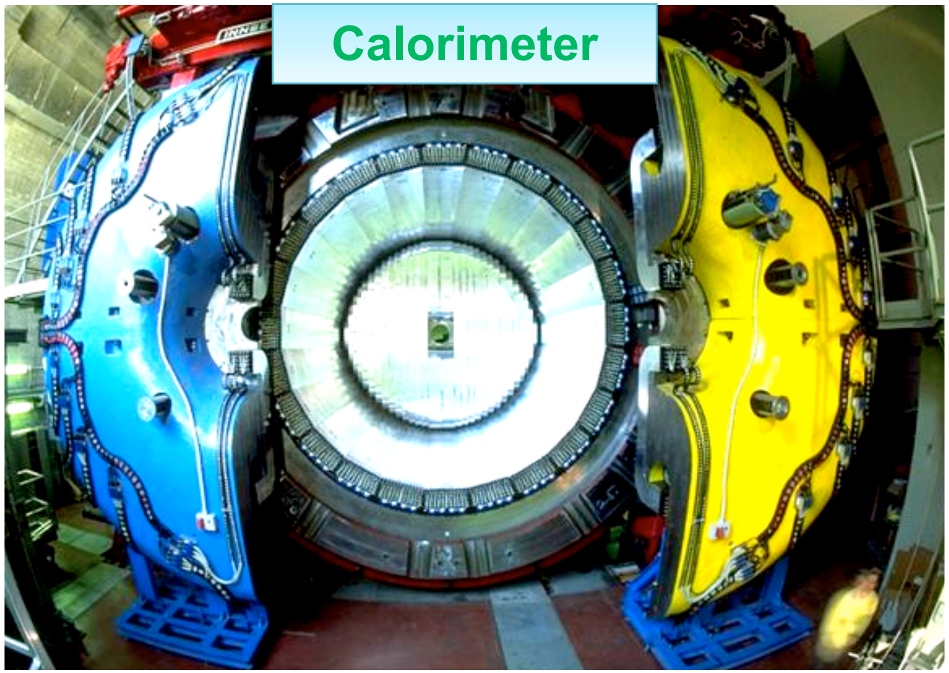
⇒ **KLOE-2**: to extend the KLOE physics program at DAFNE upgraded in **luminosity** and **energy** (up to 2.4 GeV)

References:
- KLOE-2 LoI: www.lnf.infn.it/lnfadmin/direzione/roadmap/LoIKLOE.pdf
- F.Ambrosino et al., EPJC50(2007)729
- Physics with KLOE2 experiment at the ϕ-factory, in preparation

From KLOE…



Drift Chamber



Calorimeter

Multi-purpose detector optimized for K_L physics

- Huge, transparent Drift Chamber in 5.2 kGauss field of a SC coil
- Carbon fiber walls, 55000 stereo wires, 2 m radius, 4 m long, He/CO_2 gas mixture
- Momentum resolution: $\sigma(p_T)/p_T \sim 0.4\%$

- Pb-Scintillating Fiber Calorimeter with excellent timing performance
- 24 barrel modules, 4 m long and C-shaped End-Caps for 98% solid angle coverage
- Time resolution: $\sigma_T = 54 \text{ ps} / \sqrt{E(\text{GeV})} \oplus 50 \text{ ps}$
- Energy resolution: $\sigma_E/E = 5.7\% / \sqrt{E(\text{GeV})}$

…to KLOE-2…

Minimal detector upgrades:

- Tagger for $\gamma\gamma$ physics: to detect off-momentum $e^{\pm}$ from
$$e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-\mathbf{X}$$

— LET: Low Energy Tagger (130-230 MeV)

calorimeters, LYSO + SiPM

— HET: High Energy Tagger (E > 400 MeV)

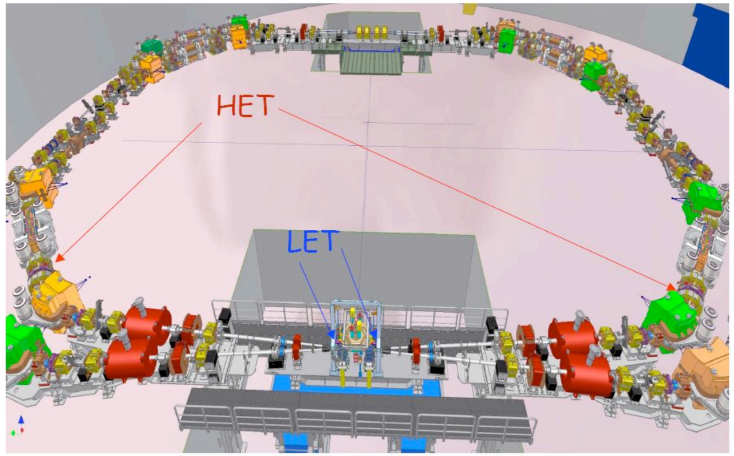
position sensitive detectors

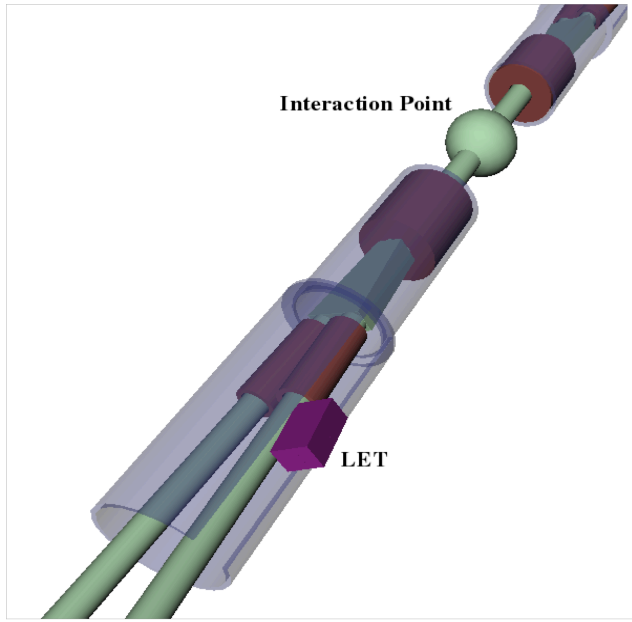
(strong energy-position correlation

$\Rightarrow$ use the DAΦNE magnets as $e^{\pm}$ spectrometer)

- Already funded by INFN

Approved $\Rightarrow$ "roll-in" : end 2009





…to KLOE-2…

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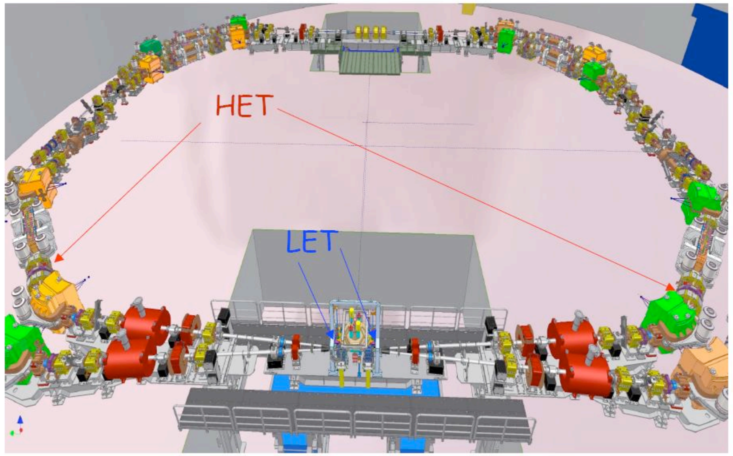
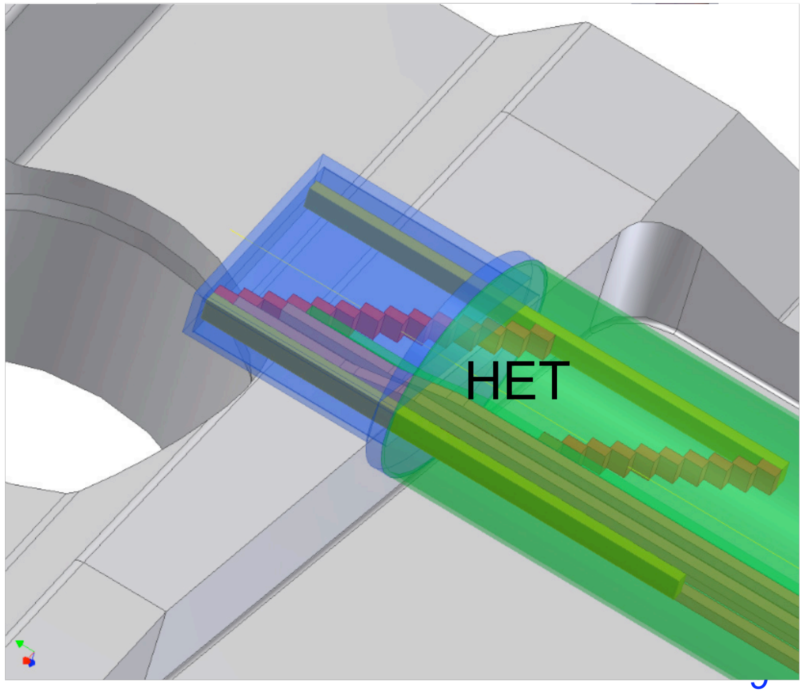
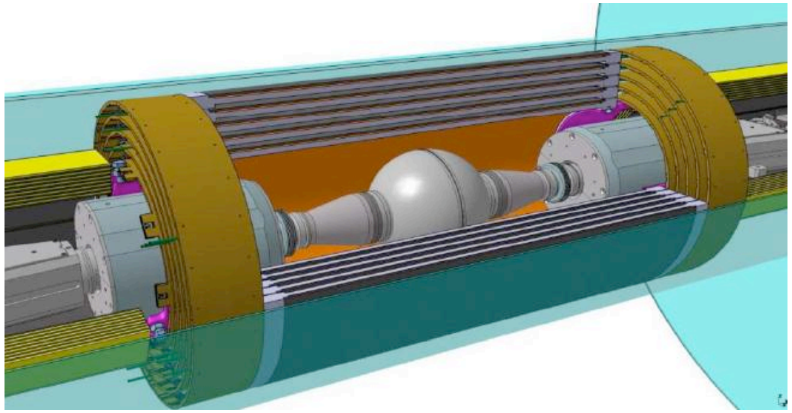


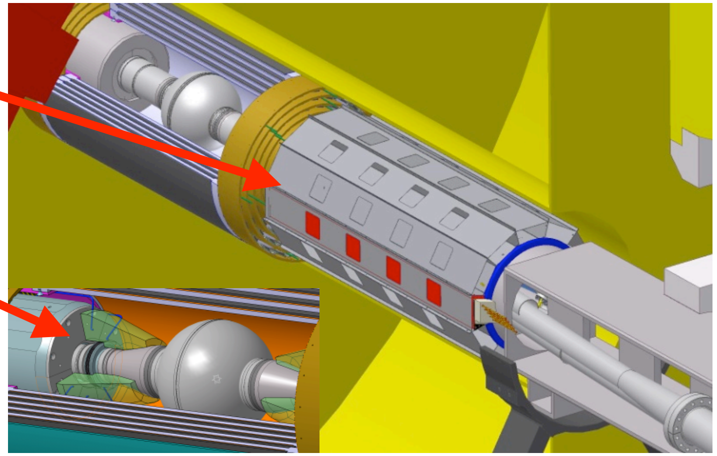


…to KLOE-2…

Major detector upgrade

- Inner tracker (between the beam pipe and the DC): 5 layers of cylindrical triple GEM:
  — improve vertex reconstruction near the IP
- QCALT: W + scint. tiles
  readout by SiPM via WLS fibers





- CCAL: LYSO crystals + APD; close to IP to increase acceptance for photons coming from the IP (min. angle: 21°→ 9°)
- Partially funded
  Time scale: installation in late 2011

KLOE-2 Physics program

- Kaon Physics
  - Test of CPT (and QM) in correlated kaon decays and test of CPT in K_S semileptonic decays
  - Test of SM (CKM unitarity, lepton universality)
  - Test of χPT (K_S decays)

- Spectroscopy of light mesons
  - $\eta,\eta',f_0,a_0,\sigma$ in ϕ radiative decays

- Hadronic cross section from $2m_\pi$ to 2.4 GeV
  - $\alpha_{em}(M_Z)$ and $(g\text{-}2)_\mu$

- $\gamma\gamma$ physics
  - Study of $\Gamma(S/PS\to\gamma\gamma)$, test of χPT, existence and properties of σ meson, PS Transition FF

- Dark Matter searches (light bosons at at O(1 GeV))

Example of CPT and QM tests:

$\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^- \ \pi^+\pi^-$

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

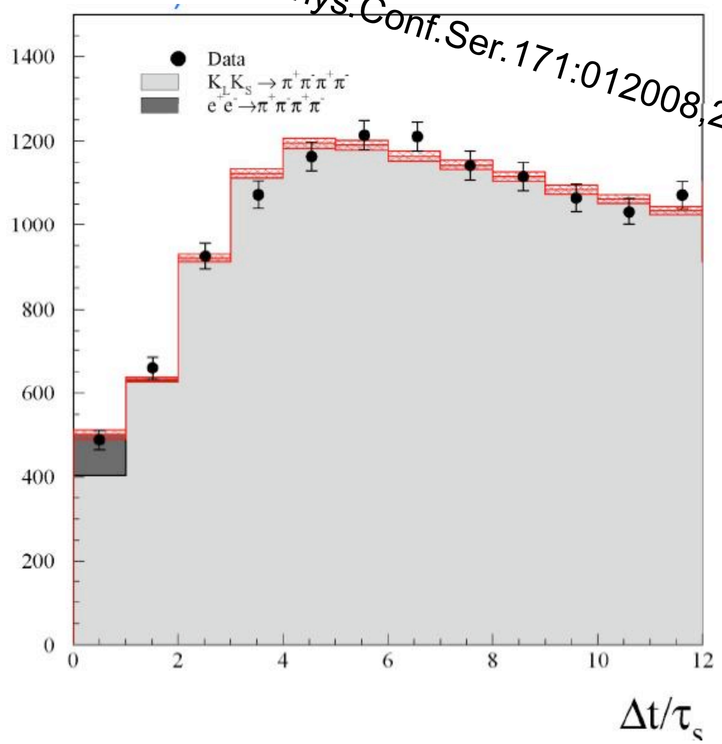
interference term modified introducing a decoherence parameter ζ.

CPT violation could also change initial state

$$|i\rangle \propto (K_S K_L - K_L K_S) + \omega(K_S K_S - K_L K_L)$$

$|\omega| < 1.0\ 10^{-3}$ @ 95% C.L:

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



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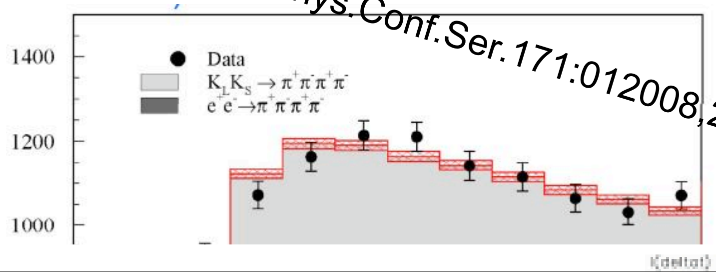


	KLOE L=1.5 fb^{-1}	KLOE-2 L=5 fb^{-1}	KLOE-2 L=50 fb^{-1} with IT
ζ_{00}	$(1.4 \pm 10.2) \times 10^{-7}$	$\pm 6.4 \times 10^{-7}$	$\pm 0.1 \times 10^{-6}$
ζ_{SL}	$(0.3 \pm 1.9) \times 10^{-2}$	$\pm 1.2 \times 10^{-2}$	$\pm 0.2 \times 10^{-2}$
γ	$(0.7 \pm 1.2) \times 10^{-21}$ GeV	$\pm 0.7 \times 10^{-21}$ GeV	$\pm 0.1 \times 10^{-21}$ GeV
Re(ω)	$(-1.6 \pm 3.0) \times 10^{-4}$	$\pm 1.7 \times 10^{-4}$	$\pm 2 \times 10^{-5}$
Im(ω)	$(-1.7 \pm 3.5) \times 10^{-4}$	$\pm 2.2 \times 10^{-4}$	$\pm 2 \times 10^{-5}$

Large improvement !

Test of Lepton Universality: R = $\Gamma(K_{e2})/\Gamma(K_{\mu2})$

-Very precise prediction from SM $R_K^{SM} = 2.477(1) \times 10^{-5}$ (accuracy at 0.04%!)

-Contribution outside SM (LFV) up to a O(1) percent

-KLOE result $R_K = 2.493(31) \times 10^{-5}$ (1.3% accuracy, **dominated** by stat err

-World average (KLOE/NA62):

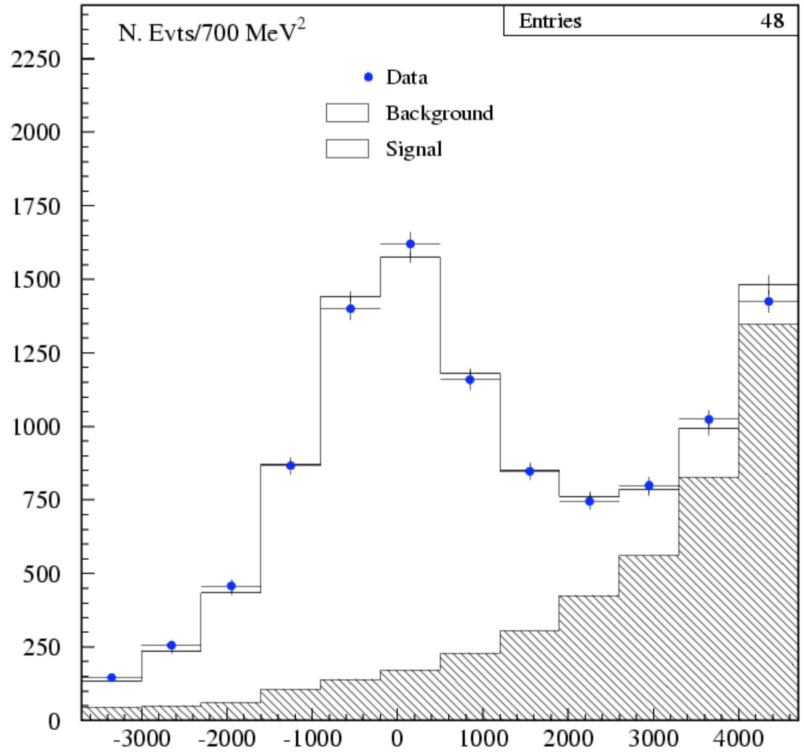
$$R_K = 2.498(18) \times 10^{-5}$$

(Accuracy ~0.56%)

Expected accuracy from NA62 ~0.3%

At KLOE-2 sensitivity will reach ~ 0.5% or better

KLOE 2.2 fb^{-1}



Inner tracker is beneficial for recovering early decays

K_S decays

$K_S \to \pi e \nu$: Test of $\Delta S = \Delta Q$ rule (i.e. $Re(x_+)$) and CPT (charge asymmetry A_S). Current accuracy on BR is 1.2% (KLOE, 400 pb^{-1}) . KLOE-2 can go to 0.2%, improving the accuracy on $Re(x_+)$ and on A_S to ~10^{-3}

$K_S \to \pi \mu \nu$: same as above but more difficult. Expected error to 0.4%

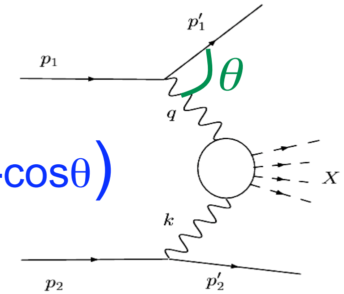
$K_S \to 3\pi^0$: purely CP violating. Expected at 10^{-9}, present limit at 10^{-7}. KLOE-2 can aim at observing the signal.

$K_S \to \gamma\gamma$: test of χPT at $O(p^4)$. Current error is 2.7%. KLOE-2 can go below 1%.

$K_S \to \pi^+\pi^-\pi^0$ another test of χPT, predictions around 10^{-7}. KLOE-2 precision to 15%.

$K_S \to \pi^0 l^+ l^-$ very important for using rare analogous decay of K_L for testing SM. Present NA48 measurement based on 7+6 events. Estimate for KLOE-2 at the same level

γγ - physics: $e^+e^- \to e^+e^- \gamma^*\gamma^* \to e^+e^- + X$

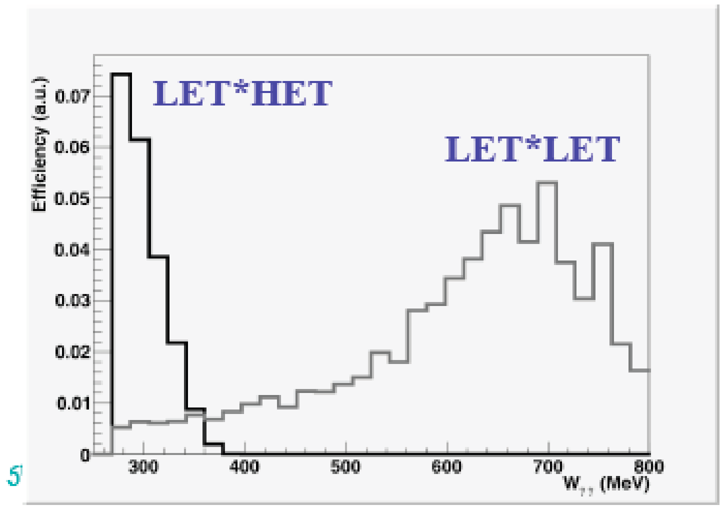


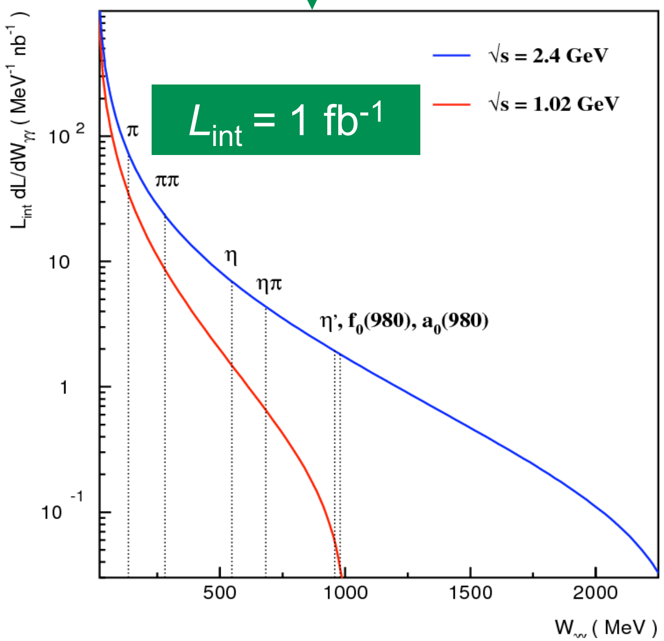
$q^2 = -2EE'(1-\cos\theta)$

- $X=\pi\pi \Rightarrow \sigma$ meson
- $X=\pi^0,\eta,(\eta')\Rightarrow \Gamma(X\to\gamma\gamma)$; Transition Form Factors $F_{X\gamma\gamma}(q^1,q^2) \Rightarrow$ LbL?
- Tagger is essential to reduce bckg from ϕ and to close the kinematics

$$\frac{dN_X}{dW_{\gamma\gamma}} = \underbrace{L_{int}\frac{dL}{dW_{\gamma\gamma}}}\,\sigma(\gamma\gamma\to X)$$

$W_{\gamma\gamma} = M_X$



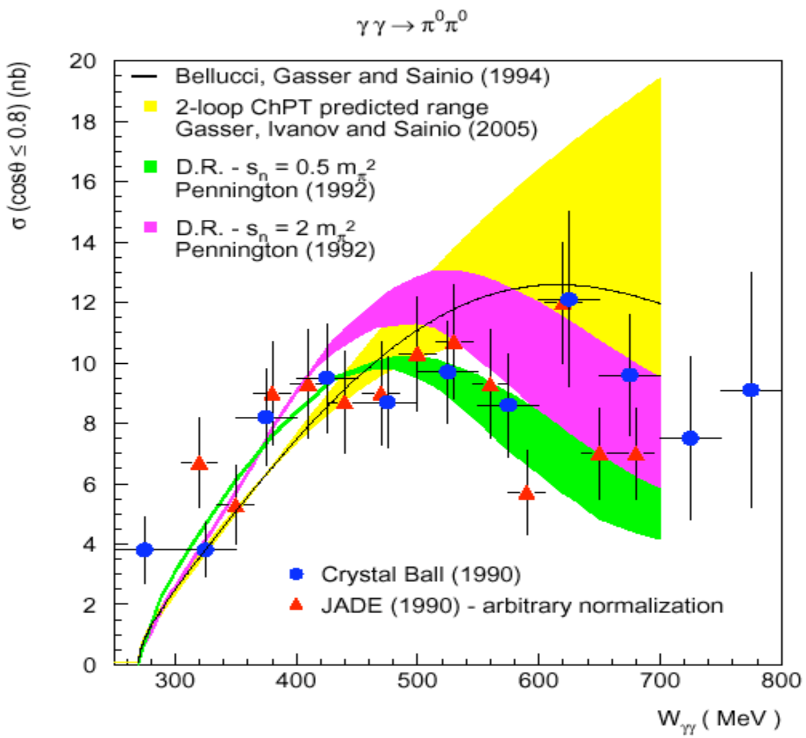


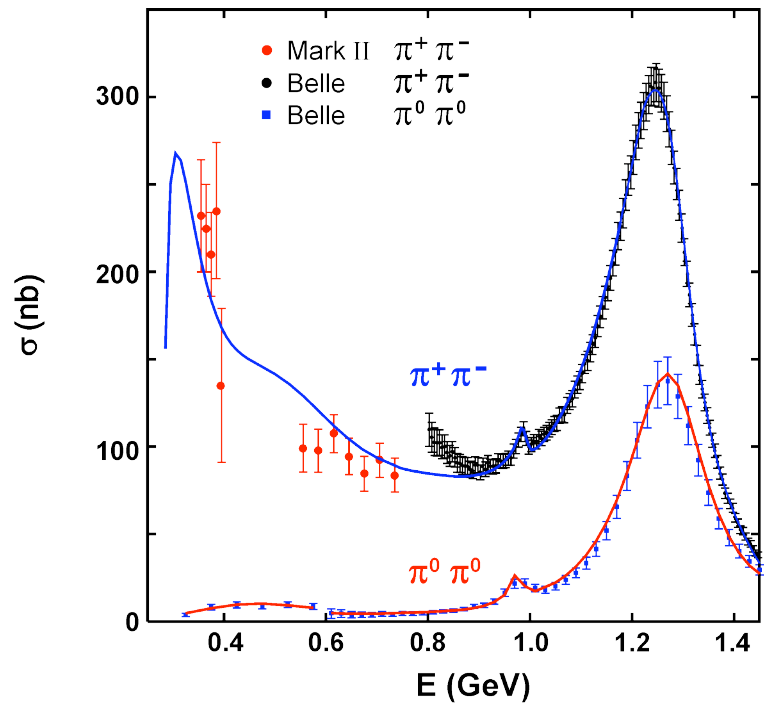
- At √s > 1.02 GeV γγ coupling of $a_0(980)$, $f_0(980)$ and larger statistics for π^0,η,η'

$\sqrt{s}$ (GeV)	π^0	η	η'
1.02	4.1×10^5	1.2×10^5	1.9×10^4
2.4	7.3×10^5	3.7×10^5	3.6×10^5

the σ meson case

cleanest channel to assess existence & nature (2q *vs* 4q) of the σ is $\gamma\gamma \to \pi^0\pi^0$ at low energy



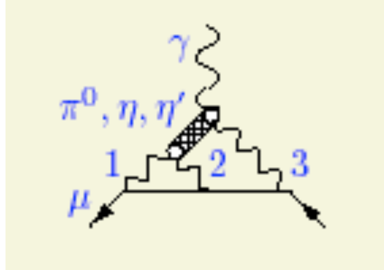


•Analysis of $\gamma\gamma\to\pi^0\pi^0$ in KLOE *in progress* (see F.Nguyen's talk)

•At KLOE-2: $\pi^0\pi^0 \Rightarrow$ golden channel (with L=5 fb^{-1} $\Rightarrow$ err. ≈ 2%); $\pi^+\pi^-$ possible?

Recent measurements from Belle limited at $m_{\pi\pi}$>0.6 GeV (see H. Nakazawa's talk)

Impact of $\gamma^*\gamma^*$ on Light-by-Light?



- The LBL contribution is dominated by the π^0 exchange with 2 virtual $\gamma \Rightarrow F_{\pi 0\gamma*\gamma*}(q_1^2,q_2^2)$
- No available data $\Rightarrow$ resort to models (N_C QCD, etc...) *(see also A. Nyffler's talk)*

ELSEVIER

Nuclear Physics B (Proc. Suppl.) 131 (2004) 162–169

The muon $g-2$ in the Standard Model and beyond

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We review the present status of the theoretical evaluation of the anomalous magnetic mome
a_μ in the Standard Model. We mainly focus on the hadronic contributions due to vacuum pol
light-by-light scattering and higher order electroweak corrections and their uncertainties. We al
new physics contributions to the muon $g-2$ and bounds on such models from the experimental

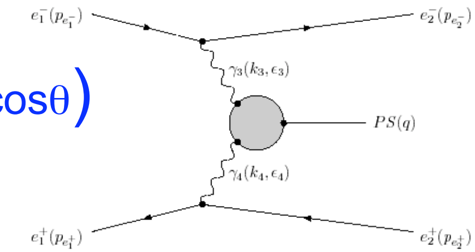
Pion-pole contribution

The contribution from the neutral pion intermediate state is given by a two-loop integral that involves the convolution of two pion-photon-photon transition form factors $\mathcal{F}_{\pi^0\gamma^*\gamma^*}(q_1^2,q_2^2)$, see Fig. 3(c). We refer to Ref. [30] and references therein for all the details. Since no data on the doubly off-shell form factor $\mathcal{F}_{\pi^0\gamma^*\gamma^*}(q_1^2,q_2^2)$ is available, one has to resort to models. We considered a certain class of form factors which includes the ones based on large-N_C QCD that we had studied in Ref. [32]. These form factors include

$F_{\pi 0\gamma*\gamma*}(q_1^2,q_2^2)$ *can be obtained from* $e^+e^- \rightarrow e^+e^-\pi^0$ $(\theta_{e\pm}>20^o)$.

q^2 is obtained by measuring E and θ of $e^\pm$

$q^2 = -2EE'(1-\cos\theta)$



Two-photon reactions with KLOE detector at DAΦNE

hep-ex/9902030

Saro Ong*

Institut de Physique Nucléaire, IN2P3-CNRS, Université Paris-Sud, 91406 Orsay Cedex, France

Abstract

We reexamine the feasibility of two-photon reactions at DAΦNE with the KLOE detector excluding the small angle tagging system. Event-rate predictions of interesting channels : $\gamma\gamma \to \pi^0$, η and $\gamma\gamma \to \pi^+\pi^-$, $\pi^0\pi^0$ are discussed.

Effects of different Form-factors in Meson-Photon-Photon Transitions and the Muon Anomalous Magnetic Moment[1]

hep-ph/0106130

Johan Bijnens and Fredrik Persson

Department of Theoretical Physics, Lund University, Sölvegatan 14A, S22362 Lund, Sweden

Interesting papers for KLOE-2!
(realistic studies on the way)

η, η' at DAFNE-2

Φ-factory = η and η' factory

$BR(\phi \to \eta\gamma) = 1.3 \times 10^{-2}$ $\Rightarrow$ **$N_\eta(20\ fb^{-1}) \sim 9 \times 10^8$**

$BR(\phi \to \eta'\gamma) = 6.2 \times 10^{-5}$ $\Rightarrow$ **$N_{\eta'}(20\ fb^{-1}) \sim 5 \times 10^6$**

Monochromatic prompt photon: clear signature

Mixing $\eta - \eta'$: Uncertainty dominated by systematics on $BR(\eta' \to \eta\pi\pi)$; improvement can come by measuring main η' BR's

η decays:

$\eta \to \pi^0\gamma\gamma$ (test ChPT; major improvements expected with 20 fb^{-1})

Dalitz decays: $\eta \to e^+e^-\gamma$, $\mu^+\mu^-\gamma$, $e^+e^-e^+e^-$ $\Rightarrow$ Transition FF

$\eta \to \pi^+\pi^-e^+e^-$ (Test of CP violation, analogous to $K_L \to \pi^+\pi^-e^+e^-$)

Improvements on forbidden/rare decays

η' decays:

Dalitz plot of $\eta' \to \eta\pi^+\pi^-$ $\Rightarrow$ scalar amplitude

$\eta' \to \pi^+\pi^-\pi^0$ $\Rightarrow$ first observation / isospin violation

Scalars at DAFNE-2

- Scalars $f_0(980)$, $a_0(980)$ will be copiously produced in the radiative decay of the ϕ

- With 20 fb^{-1} the decay $\phi \rightarrow a_0/f_0\gamma$, $a_0/f_0 \rightarrow K^+K^-$ (K^0K^0) (expected BR ~ $10^{-(6\text{-}8)}$) will be well measured (10^5 K^+K^- and 10^3 K^0K^0). $\Rightarrow$direct measure of the g_{fKK} coupling

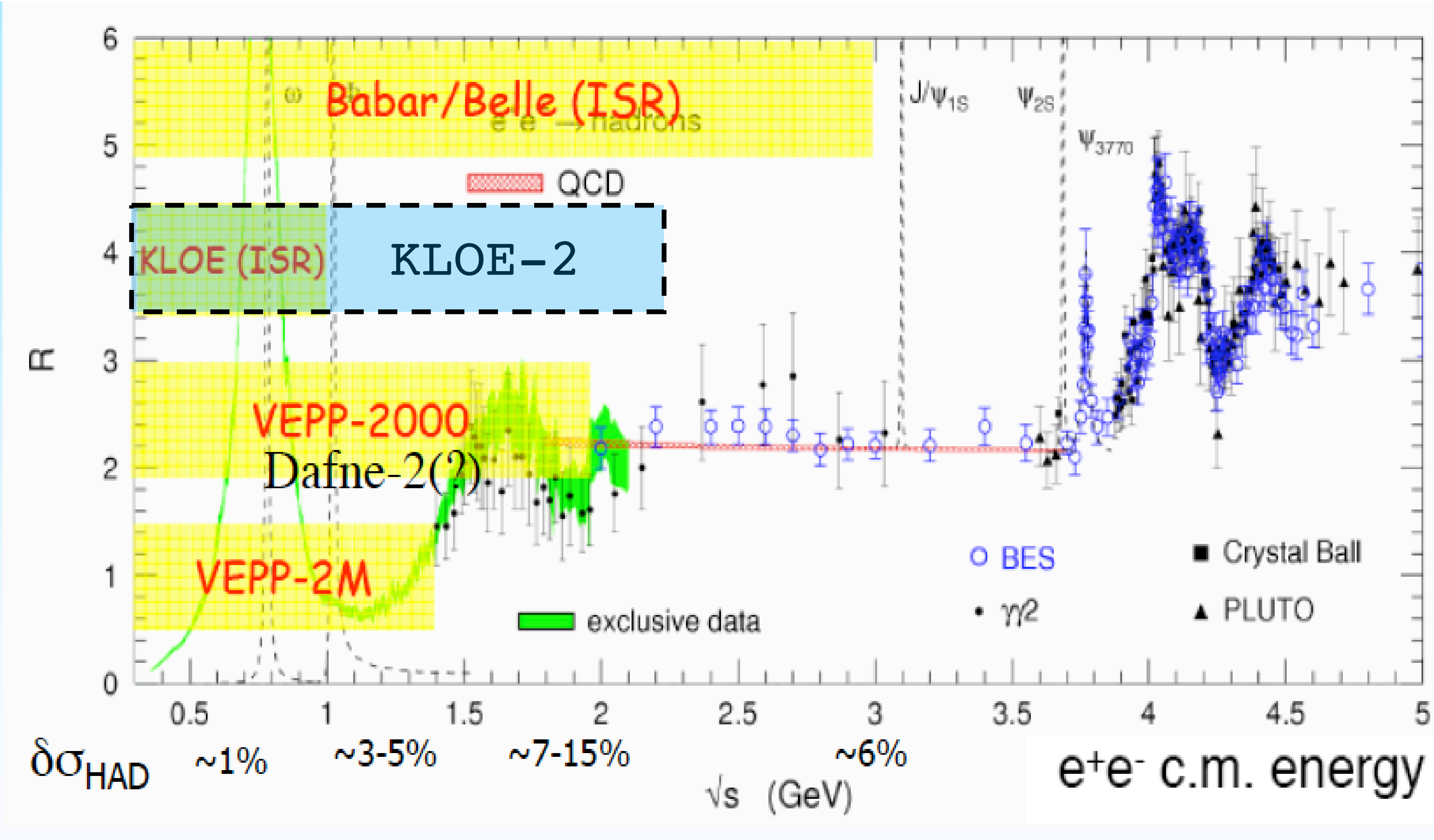
(See P. Gauzzi's talk)

Measurement of hadronic cross sections from $2m_\pi$ to 2.4 GeV

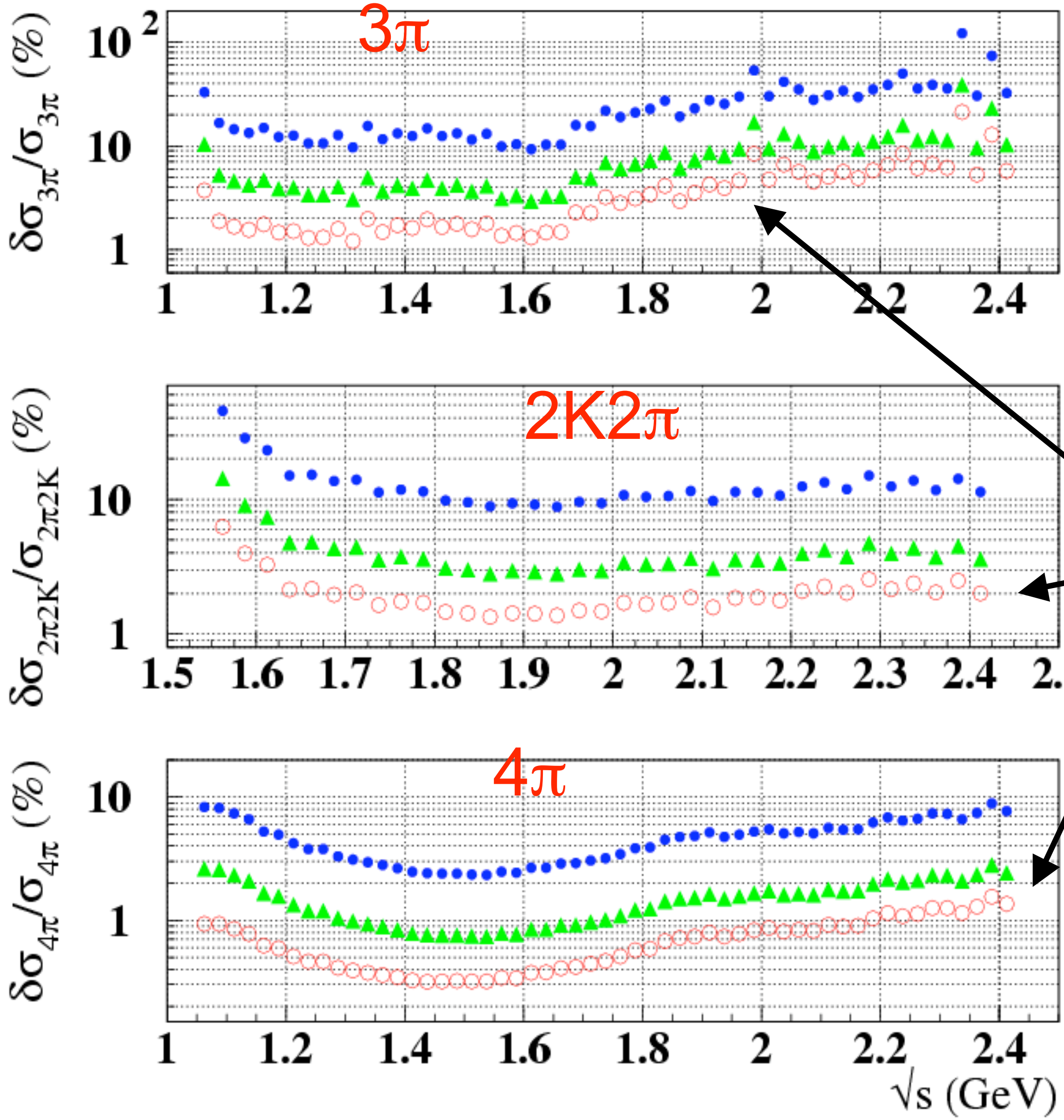
➔Hadronic contribution to $(g\text{-}2)_\mu$ and α_{em}

➔ Spectroscopy of vector mesons

N.B. “”competition” with B-factories ISR, and VEPP-2000



Impact of DAFNE-2 on exclusive channels in the range [1-2] GeV with a scan (Statistical only)



BaBar, with the published L_{int} per point (90 fb^{-1})

BaBar, with 10 × (the present L_{int})

DAFNE-2, with 20 pb^{-1} per point (<1 week @10^{32} cm^{-2}s^{-1}),

- DAFNE-2 is **statistically** better than O(1ab^{-1}) B-factories
- Improvement on systematics come as well!

Of course ISR can be done as well!

Conclusion

- New DAFNE interaction scheme (crab waist) successfully implemented, luminosity increased by a factor of ~3 (L_{MAX}~4 $10^{32}cm^{-2}s^{-1}$)

- KLOE-2: extended KLOE physics program at DAFNE upgraded both in **luminosity** O(20 fb^{-1}) and **energy** ($2m_\pi<\sqrt{s}<2.4$ GeV)

- Rich physics program:
  - Kaon physics - e.g. quantum interferometry, K_S semileptonic decays, $K_S \to 3\pi$, $K \to e\nu$
  - Scalar/PS physics - $f_0/a_0 \to KK\gamma$; $\eta-\eta'$-mixing, $\eta \to \pi\gamma\gamma$, Dalitz and double-Dalitz decays, CP violation,...
  - $\gamma\gamma$ physics ($\Gamma(S/PS \to \gamma\gamma)$, test of χPT, σ meson, PS Transition FF LbL?)
  - Precision measurement (~1%) of the hadronic cross section $2m_\pi<\sqrt{s}<2.4$ GeV
  - Search for new physics at O(1 GeV) (Light bosons? Dark Matter particles?)

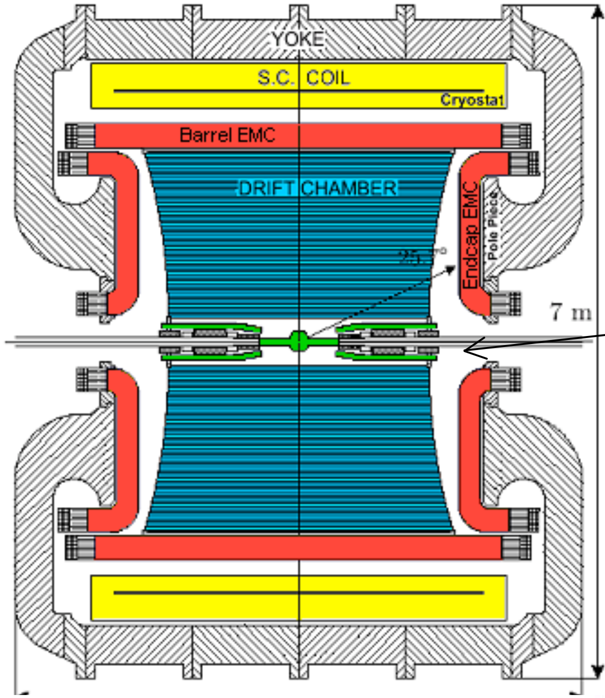
- KLOE detector will be upgraded by a $\gamma\gamma$ tagger (funded), an Inner Tracker, and calorimeters in the forward regions (partially funded)

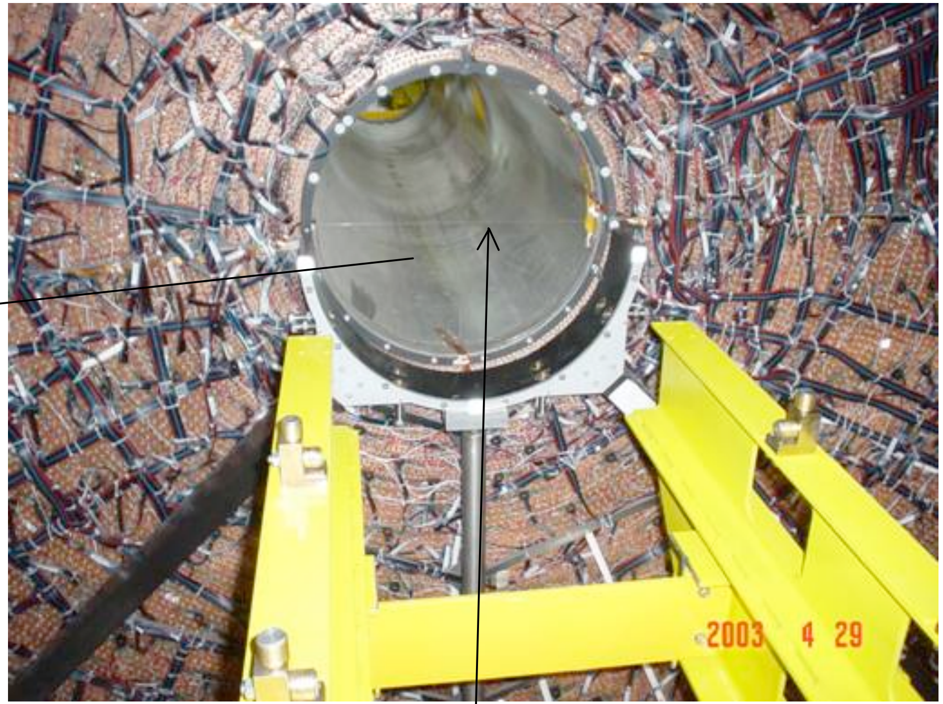
- KLOE-2 will restart data taking at the beginning of next year. The next 3 years are essentially approved, while the rest of the running will depend very much on the future of the laboratory (SuperB?)

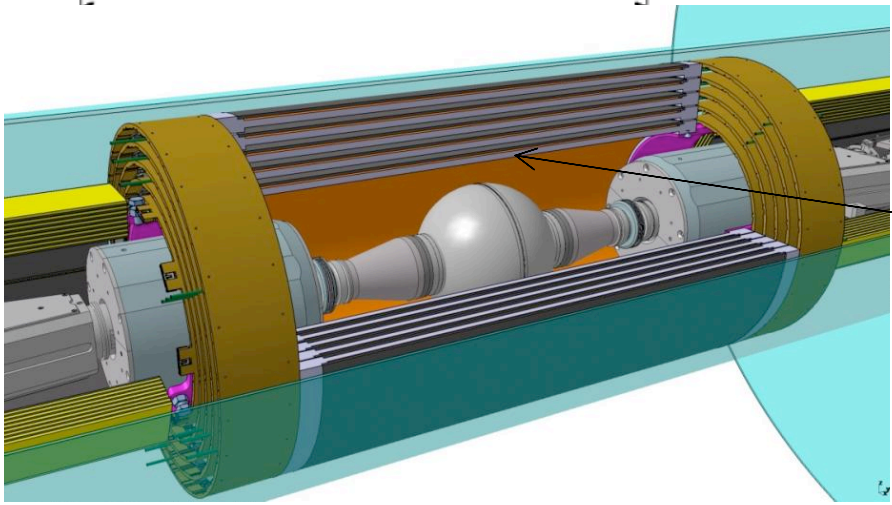
New collaborators are WELCOME!!!

SPARES

The Inner Tracker







IT to be inserted inside KLOE

- Inner radius **127 mm** (20 τ_s) to preserve K_L-K_s interference region
- Outer radius **215 mm** for safe installation inside the DC

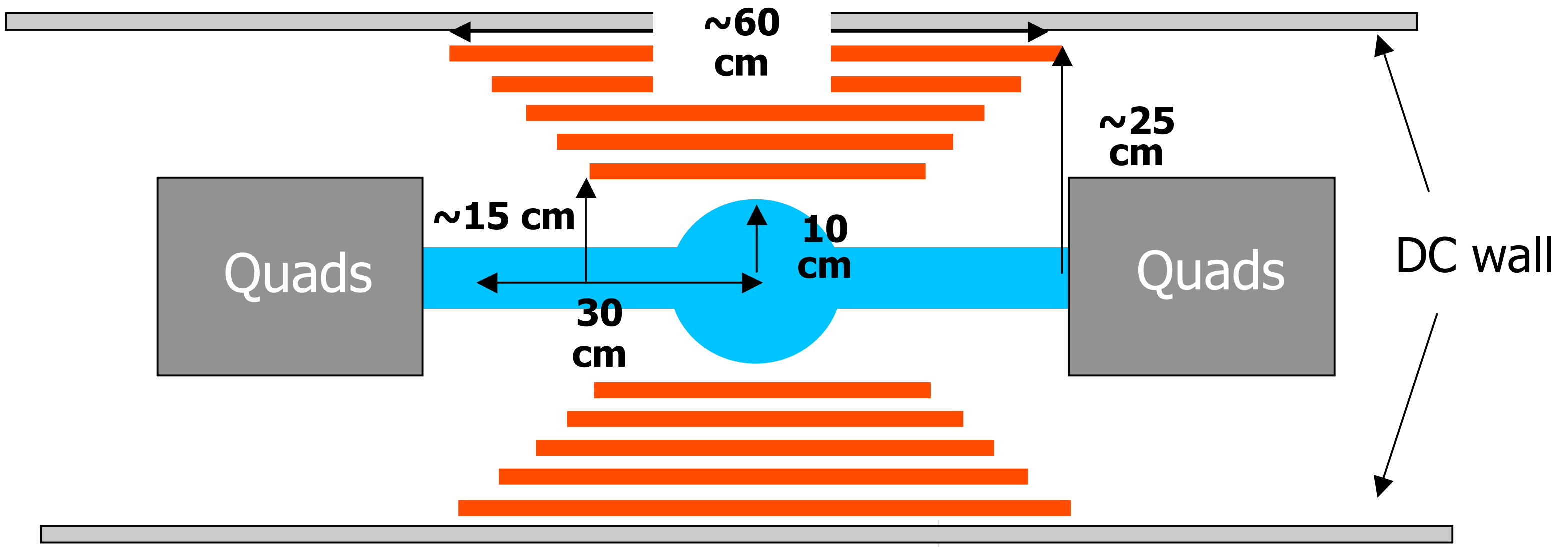
The KLOE-2 detector

A project for the continuation of the KLOE physics program on the upgraded machine, has been put forward since early 2006

It is proposed to improve the performance of the detector by the implementation of a few modifications to its design:

- The insertion of an inner tracker
- The modification of the quadrupole calorimeters (QCAL)
- The insertion of crystal calorimeters in the low θ region
- The insertion of a tagging system for $\gamma\gamma$ events

Inner Tracker: the C-GEM project (novel technology)



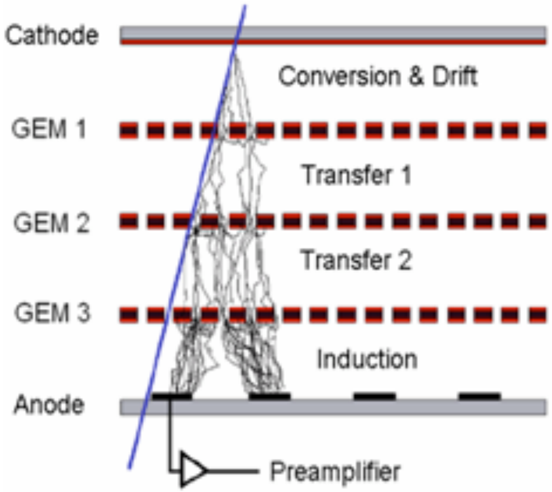
- Improve vertex reconstruction
- Improve acceptance for low-Pt tracks
- Light material in order to minimize m.s. and γ absorbition

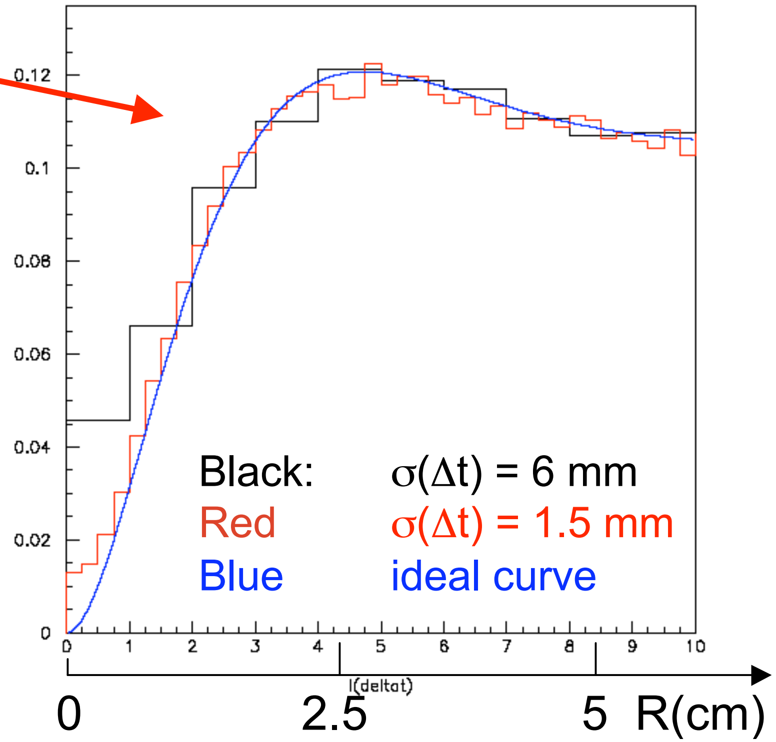
→Cylindrical triple GEM

(G.Bencivenni et al.)

$\sigma(r\phi) = 200\ \mu m$

$\sigma(z) = 500\ \mu m$



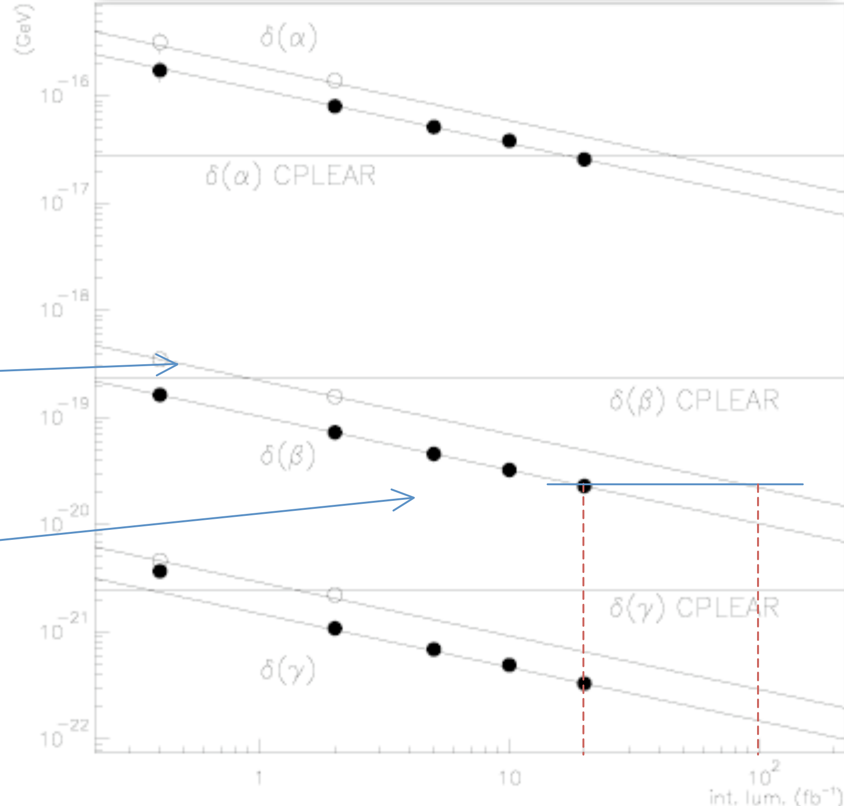


Need for an Inner Tracker

Simulation results for a π track from $K_S \to \pi\pi$

	Δx @pca	Δz @pca	Δp_x @pca	Δx @vertex
IT	0.6 mm	0.9 mm	1.2 MeV/c	1.9 mm
No IT	1.7 mm	2.2 mm	1.6 MeV/c	4.9 mm

Sensitivity on CPT violation parameters on K^0 interference (αβγ)



KLOE measurement ($\sigma_{\Delta t} = \tau_S$)

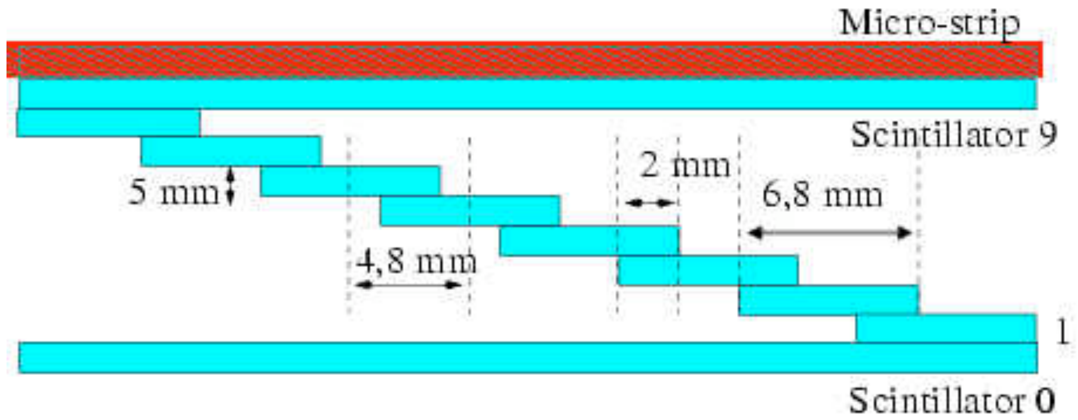
KLOE-2 prevision ($\sigma_{\Delta t} = 0.25\ \tau_S$)

Factor of 10 improvement of present error feasible with **20 fb^{-1}** (100 fb^{-1} needed witout IT)

$\gamma\gamma$ tagger

Detection of $e^{\pm}$ emitted at small angle

Detector of the type of that already in use by the GRAAL experiment in Grenoble.



Position detector: μstrip silicon detector + plastic scintillator hodoscope

We are presently studying together with the AD the proper location of the detector along the beam line and its integration with the machine components

In May (and Nov) 06 The LNF Scientific Committee review the project

2 The future programme

2.1 The physics case

The physics programme outlined in the three EoIs and LoIs submitted (KLOE2, AMADEUS and DANTE) is very important, solid, and compelling. It will offer unique opportunities for new and improved SM measurements in the sectors of flavour and of strong interactions, as well as for the exploration of the limits of the SM and of its foundations. Higher-statistics running at the ϕ peak will improve the knowledge of kaons, possibly exposing anomalies consistent with the presence of new physics, and will probe with unmatched sensitivity possible violations of CPT and decoherence phenomena in Quantum Mechanics. No other facility worldwide, either existing or planned, would be able to carry out this part of the physics programme, which the Committee strongly supports. AMADEUS also appears to be an ideal experiment to explore and study in detail the physics of possible deeply-bound kaonic states using the high kaon statistics available.

(DAFNE-2)

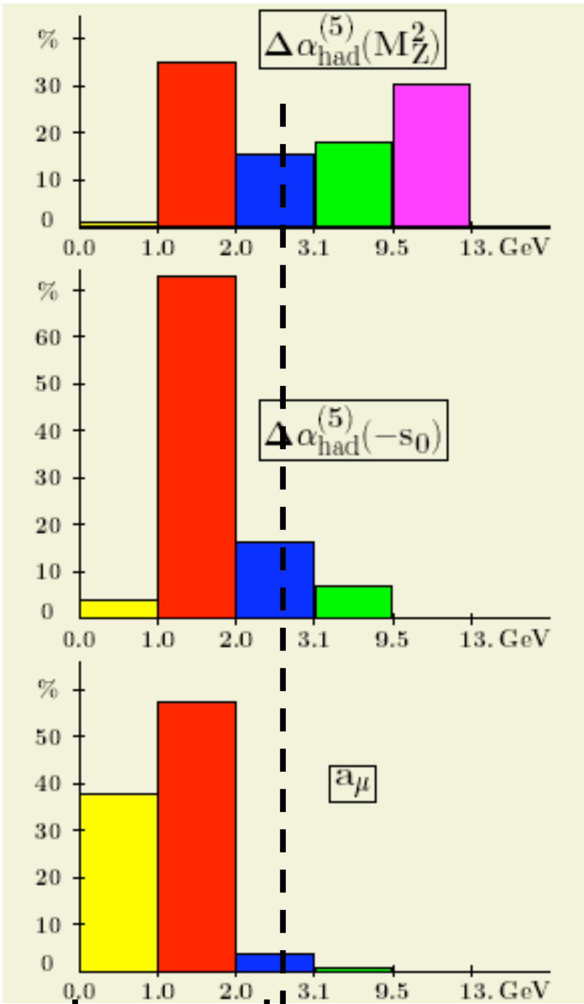
The access to higher collision energies promised by DANAE will open complementary possibilities, most notably the measurement of $R(e^+e^-)$ at the 1% level or better, the exploration of $\gamma\gamma$ reactions and the associated opportunities for scalar meson studies, and the measurement of proton and neutron time-like form factors. The measurement of R would lead to a determination of $\alpha_{EM}(M_Z)$ with the accuracy necessary to match the precision of future electroweak data from the ILC. While a comparable accuracy may also emerge in the future from other experiments (e.g. BES, VEPP2000, or the Super-B factory), the relevance and difficulty of the measurement are such that performing it at DANAE is highly desirable. The opportunity to perform this measurement by itself justifies the effort to increase the DAΦNE beam energy.

Comparison of error profiles for $\alpha_{em}(M_Z)$ and a_μ

Direct integration of energy points for $\alpha_{em}(M_Z)$

Use of Adler function (It allows to use pQCD in a *safer* way down to 2.5 GeV) for $\alpha_{em}(M_Z)$

Direct integration of energy points for a_μ

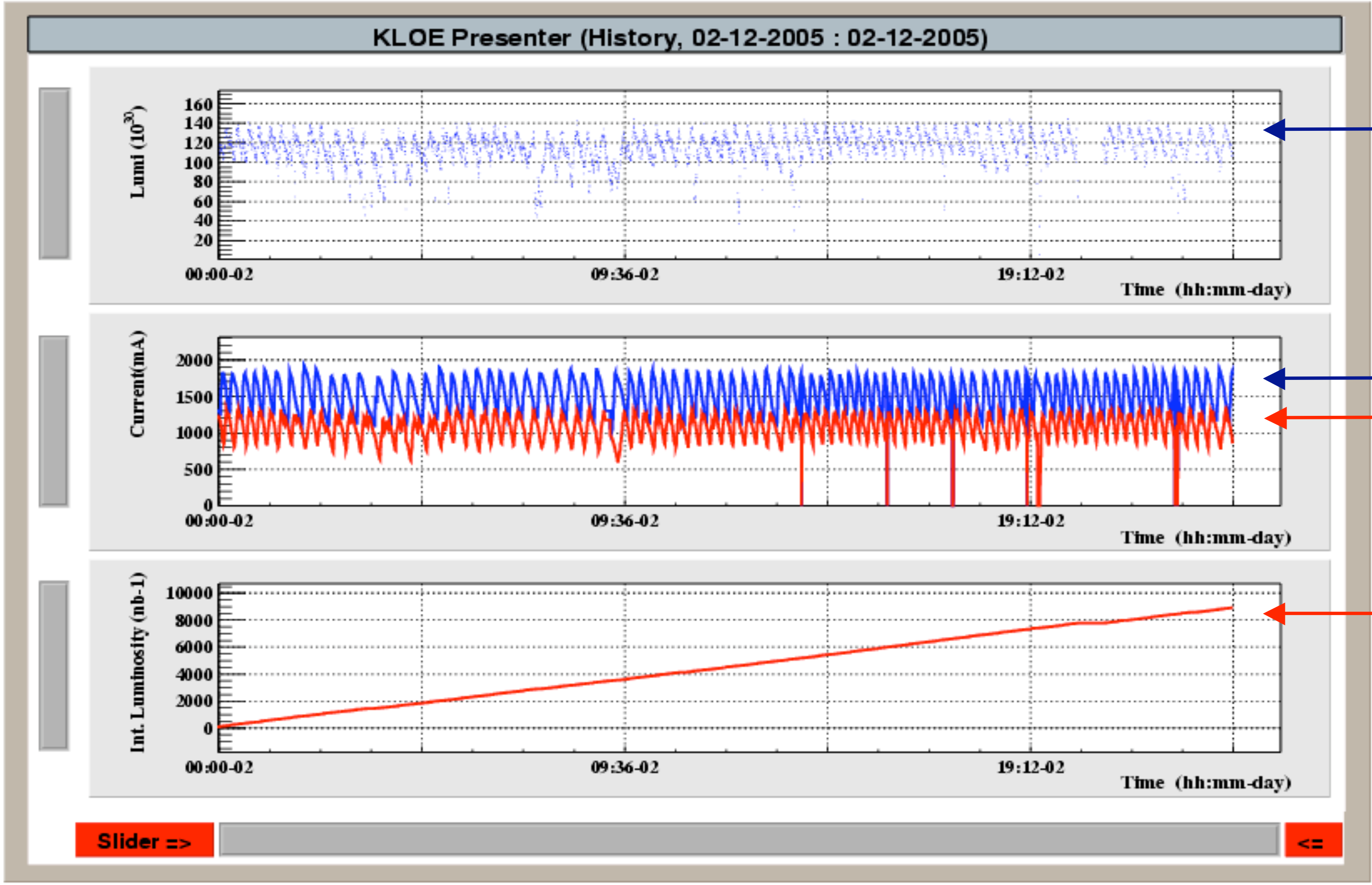


δR at 1% in the region $\sqrt{s}$ < 10 GeV ⇒ improvement of ~3 in $\delta\alpha(M_Z)$

δR at 1% in the region $\sqrt{s}$ < 10 GeV ⇒ improvement of ~6 in $\delta\alpha(M_Z)$ (Theory must improve!) .
1% in the region $1<\sqrt{s} < 2.5$ GeV (which is known with 5% accuracy) ⇒ improvement of ~4 on $\delta\alpha(M_Z)$

***Extremely** important region since its accounts for:*
*-**80%** of the total error on $\Delta\alpha^{(5)}_{had}$*
(using Adler function)
*- **95%** of the tot error on a_μ*

KLOE daily data taking (2005)



$L = 1.4 \cdot 10^{32}$ $cm^{-2}s^{-1}$

$I_- = 1.6$ A

$I_+ = 1.1$ A

$\int L dt = 8\ pb^{-1}$