Status of KLOE and DAFNE

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For the **KLOE** collaboration

1. Overview of physics at a ϕ - factory
2. The collider DAFNE
3. The KLOE experiment
4. Overview of KLOE results
   → |Vus| from K_L decays
   → Hadronic corrections to g-2
5. Conclusions and Outlook

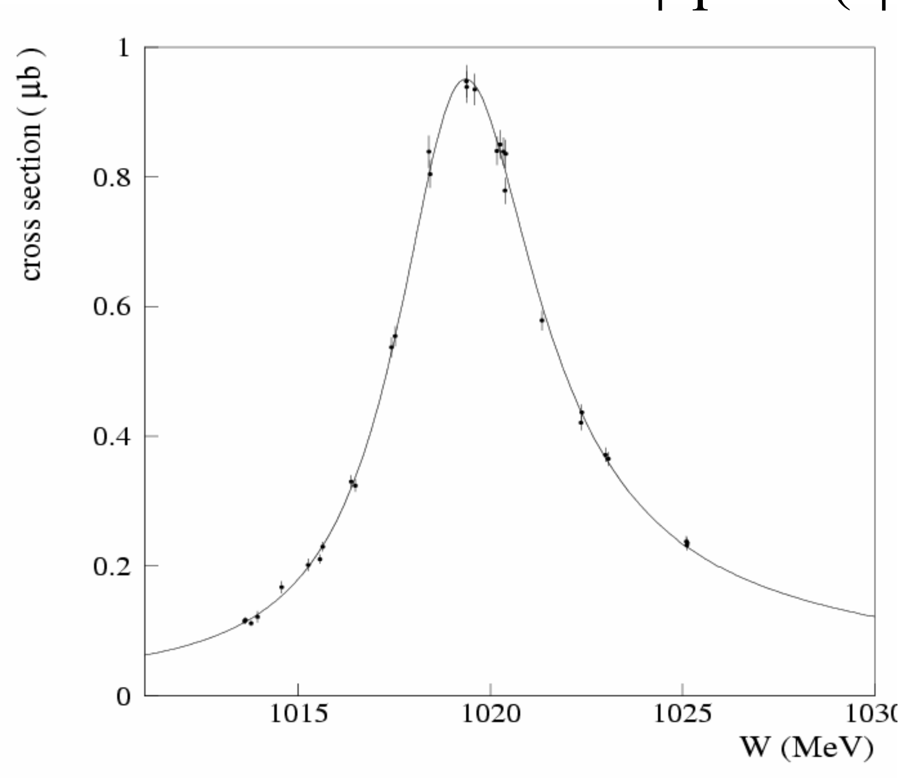
1. Overview of Physics at a φ - factory

DAFNE: e^+e^- collider at center of mass energy W=1020 MeV at *Laboratori Nazionali di Frascati* INFN

W=1020 MeV ➔ φ meson peak

$\sigma(e^+e^- \rightarrow \phi \rightarrow \text{all}) \sim 3\ \mu b$

W scan around the φ peak ($\phi \rightarrow K_S K_L$)



Why at the ϕ peak ? Because it is "a source of interesting physics"

BRs of ϕ decay channels (*from PDG*)

1) Kaon pairs:

→ K^+K^-	= 49.1%	
→ K^0K^0	= 34.0%	

2) 3 pions

→ $\pi^+\pi^-\pi^0$	= 15.4%	(including $\rho\pi$)

3) Radiative decays

→ $\eta\gamma$	= 1.3%	
→ $\pi^0\gamma$	= 1.2×10^{-3}	
→ $\eta'\gamma$	= 6.2×10^{-5}	
→ $\pi\pi\gamma$	= $\sim 10^{-4}$	(including $f_0(980)\,\gamma$)
→ $\eta\pi^0\gamma$	= $\sim 10^{-4}$	(including $a_0(980)\,\gamma$)

4) Conversion decays

→ ηe^+e^-	= 1.1×10^{-4}	
→ $\pi^0e^+e^-$	= 1.1×10^{-5}	

Kaon physics:

monochromatic (p = 110 MeV/c) kaons (charged and neutrals);
"coherent" production ➔ mutual "tagging"
Neutral kaons are produced in a pure quantum $J^{PC} = 1^{--}$ state:
$\lambda_S = 6$ mm $\lambda_L = 3.5$ m

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

➔Pure K_S and K_L beams → K_S , K_L *physics*
➔Kaon *interferometry*
➔High statistics of $K^{\pm}$; $K^{\pm}$ decays and asymmetries

3 pions

$\phi \to \rho\pi$ ➔samples of ρ^+, ρ^- and ρ^0 ➔ **CPT** and **Isospin** tests
Study of direct $\phi \to \pi^+\pi^-\pi^0$ coupling

Radiative decays (1):

Since ϕ = <ss> state (almost pure)
$\phi \rightarrow$ **M**γ is related to the ***s-content* of M**

➔Nature of scalar mesons (**f_0(980), a_0(980), σ**)
➔Pseudoscalar mixing angle (comparison of $\phi \rightarrow \eta\gamma$ and $\phi \rightarrow \eta'\gamma$)

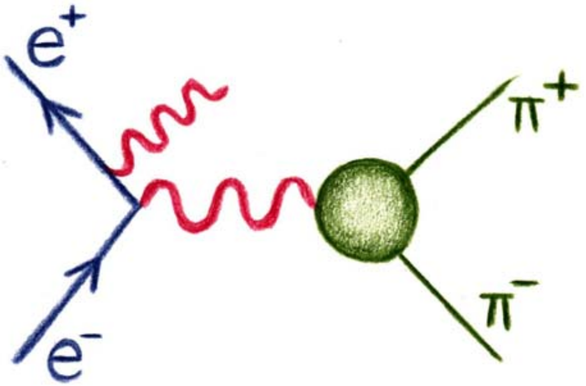
Radiative decays (2):

Source of monochromatic pseudoscalar mesons;
$\phi \rightarrow \eta\gamma$: E=363 MeV photon + η decay σ = 30 nb
$\phi \rightarrow \pi^0\gamma$: E=501 MeV photon + π^0 decay σ = 3 nb
$\phi \rightarrow \eta'\gamma$: E= 60 MeV photon + η' decay σ = 0.2 nb
➔ **η and η' physics**

Radiative Return:

Machine @ W=1020 MeV

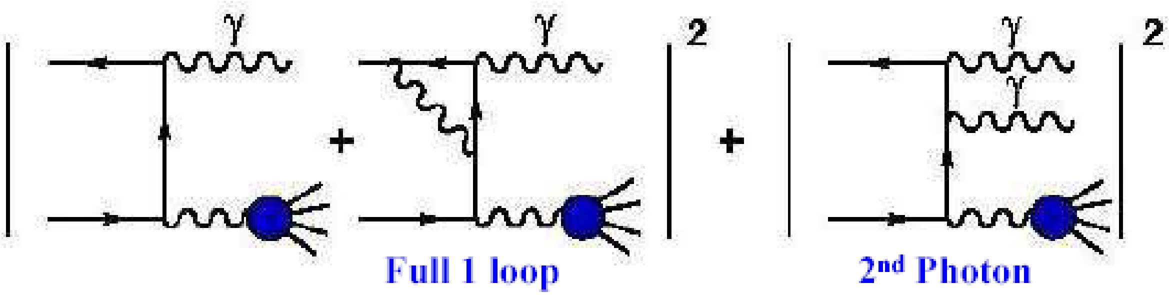
➔ $\sigma(e^+e^- \rightarrow \text{hadrons})\ 2M_\pi < Q < W$



$$Q^2 \frac{d\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma)}{dQ^2} = \sigma(e^+e^- \rightarrow \pi^+\pi^-)H(Q^2)$$

$H(Q^2)$ is the "radiator" function fully provided by Montecarlo based on QED (Eva, Phokhara,… big effort from theoreticians)

PHOKHARA = full NLO - calculation to $\pi\pi\gamma$ initial state radiation

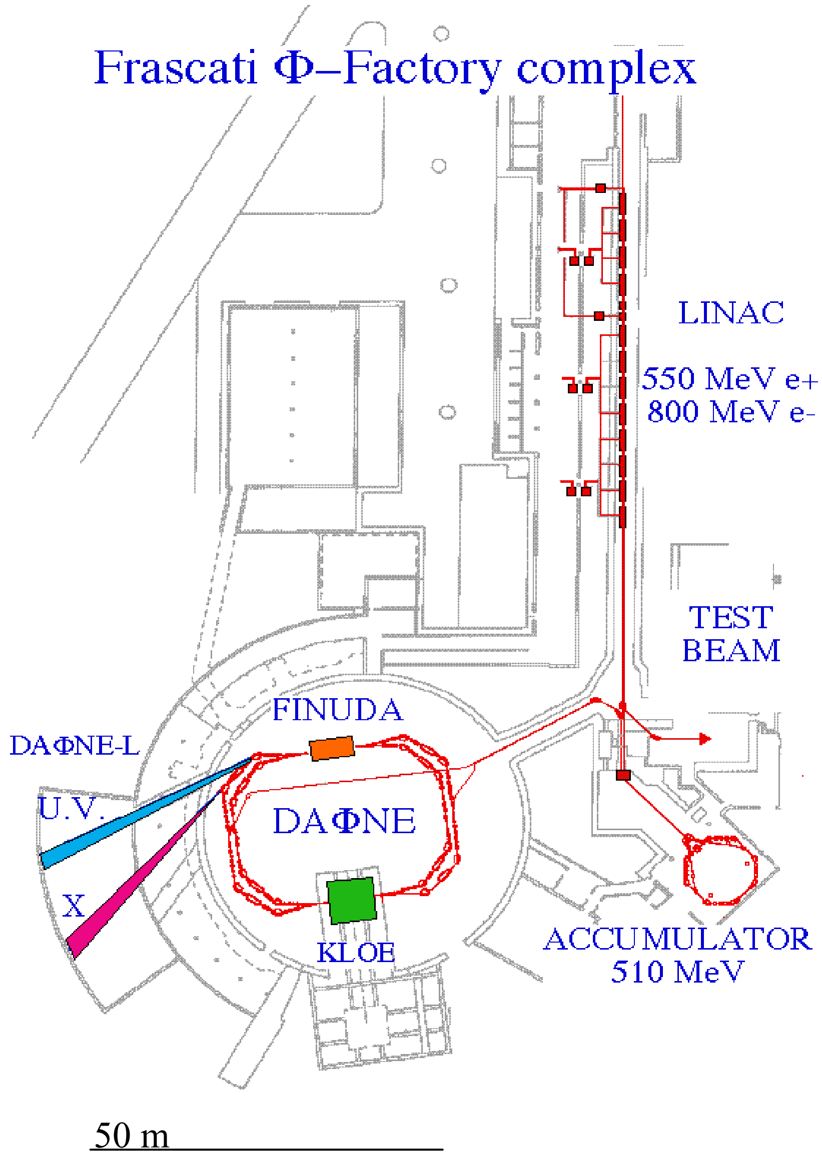


H. Kühn, H. Czyz, G. Rodrigo

$\sigma(e^+e^- \rightarrow \text{hadrons})\ [2M_\pi < Q < M_\phi]$ ➔ 67% of error on a_μ(hadr)

"Fundamental ingredient for precision test of the Standard Model"

2. The collider DAΦNE



2 separate beams
→ **2** interaction regions
(cannot run simultaneously)

120 bunches / beam

Bunch dimensions @ I.R.:
~ **20 μm** × **2 mm** × **1 cm**

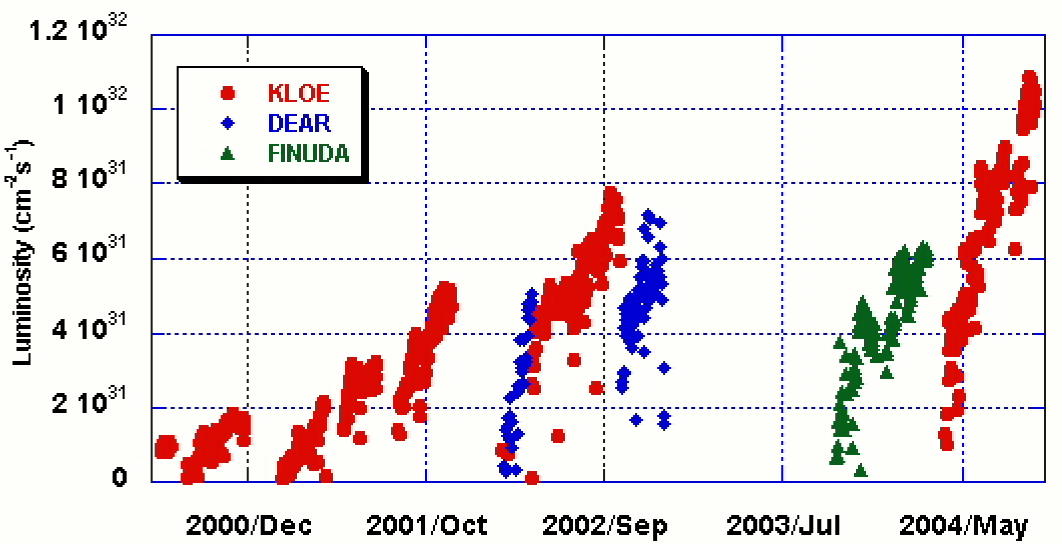
Bunch spacing = **2.7 ns**

Continuous alternate injection
(topping up) → every **20-30 mins**

Project luminosity = **5 ×10^{32} cm^{-2} s^{-1}**

DAΦNE "history":

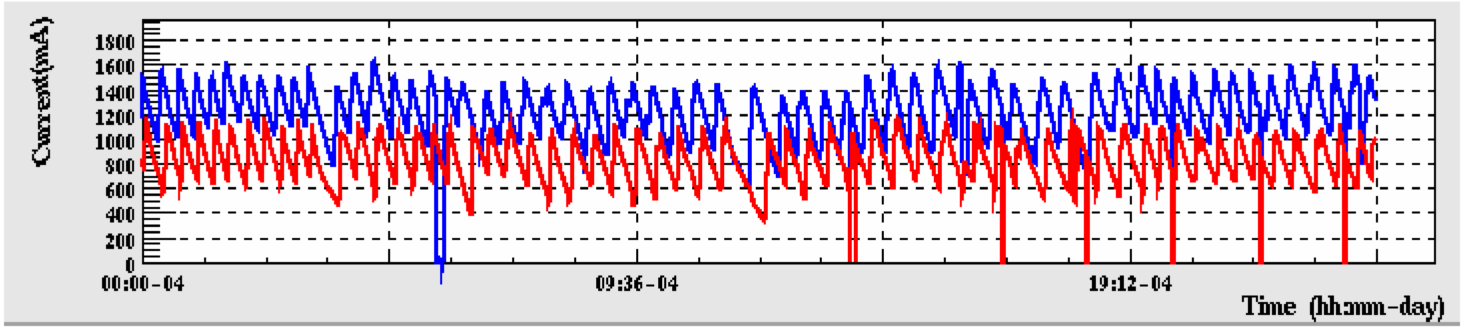
Spring 1999	First collisions: **KLOE** test run	
2000	**KLOE** Run	$L_{int} = 20\ pb^{-1}$
2001	**KLOE** Run	$L_{int} = 200\ pb^{-1}$
2002	**KLOE** Run	$L_{int} = 250\ pb^{-1}$
2002	**DEAR** Run	$L_{int} = 110\ pb^{-1}$
2003-2004	**FINUDA** Run	$L_{int} = 250\ pb^{-1}$
2004	**KLOE** Run	$L_{int} = 420\ pb^{-1}$ (up to date)



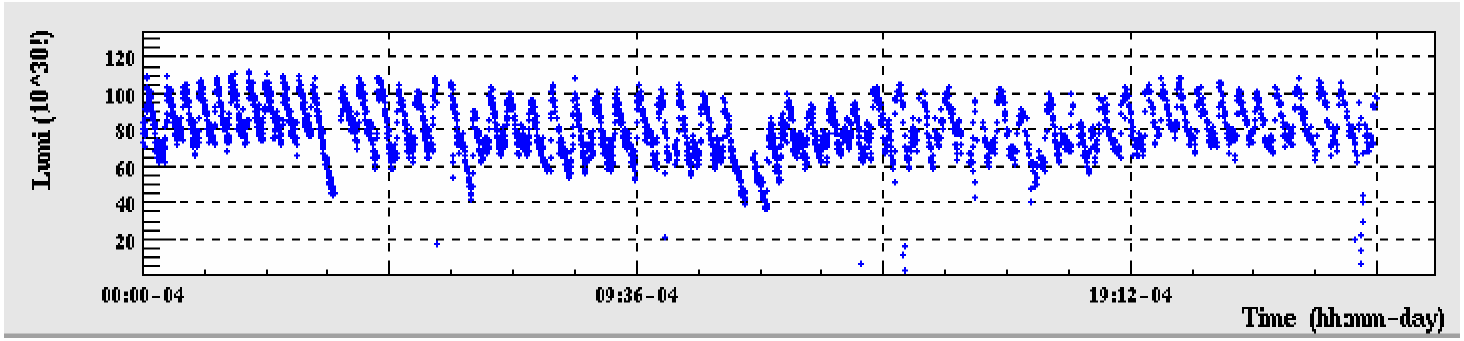
Luminosity progress

1 standard day of **DAFNE/KLOE** operation (4/10/2004)

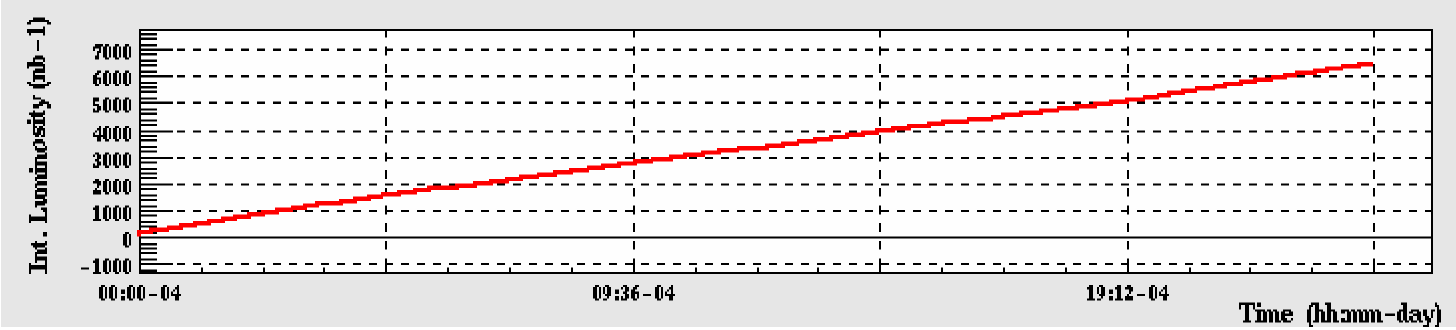
Blue = e^- curr.
Red = e^+ curr.



Instantaneous Luminosity



Integrated Luminosity
(6 pb^{-1} /day)



$L = 10^{32}\ cm^{-2}\ s^{-1}$ ➔ ~ 300 ϕ /s ➔ **2.5×10^5 η / day , 1500 η' / day**

3. The KLOE experiment

A. Aloisio,[g] F. Ambrosino,[g] A. Antonelli,[c] M. Antonelli,[c] C. Bacci,[m]
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L. Pontecorvo,[k] M. Primavera,[e] P. Santangelo,[c] E. Santovetti,[l]
G. Saracino,[g] R. D. Schamberger,[n] B. Sciascia,[c] A. Sciubba,[j,c] F. Scuri,[i]
I. Sfiligoi,[c] A. Sibidanov,[c,h] T. Spadaro,[c] E. Spiriti,[m] M. Tabidze,[c,o]
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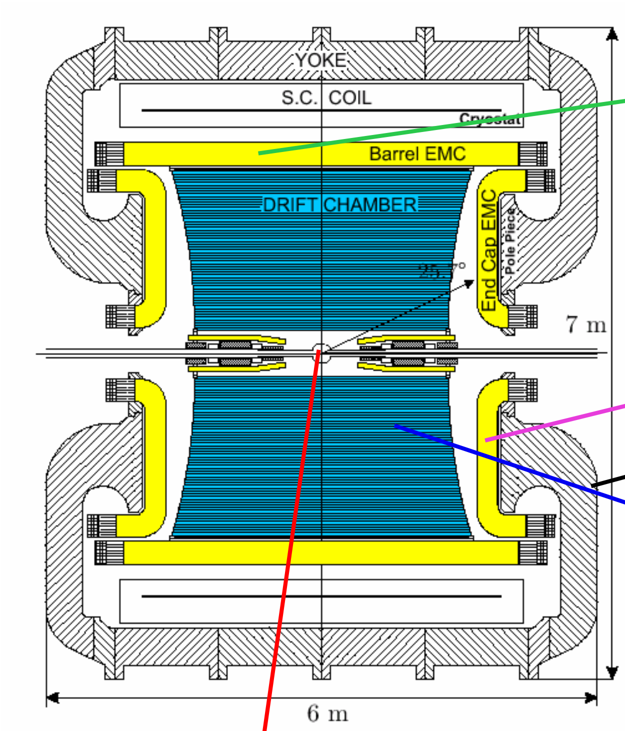
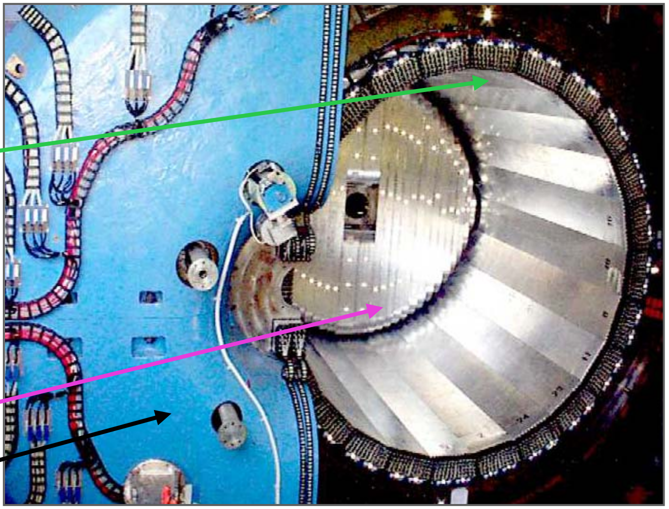
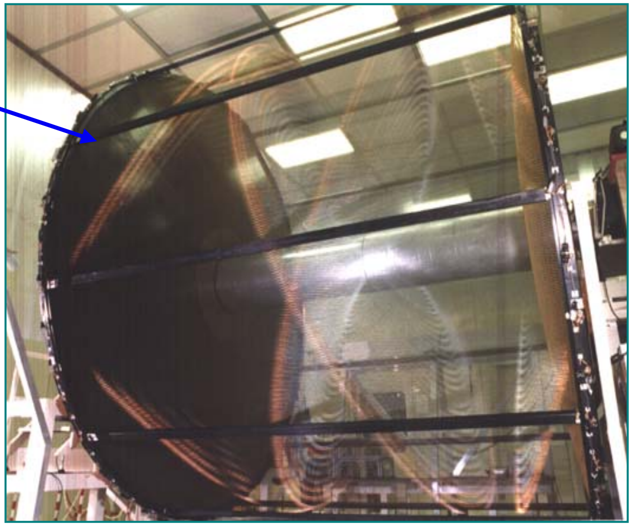
The KLOE detector



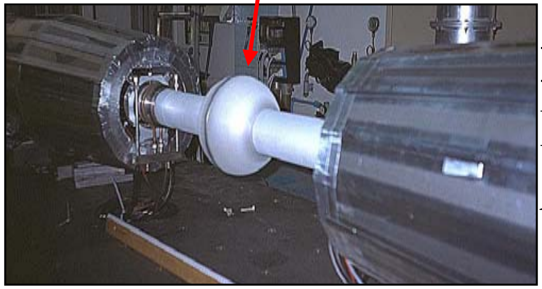


Pb-SciFi Calorimeter
(barrel + endcap,
15 X_0 depth, 98%
solid angle coverage)

Large volume Drift Chamber
(13K cells, He gas mixt.)



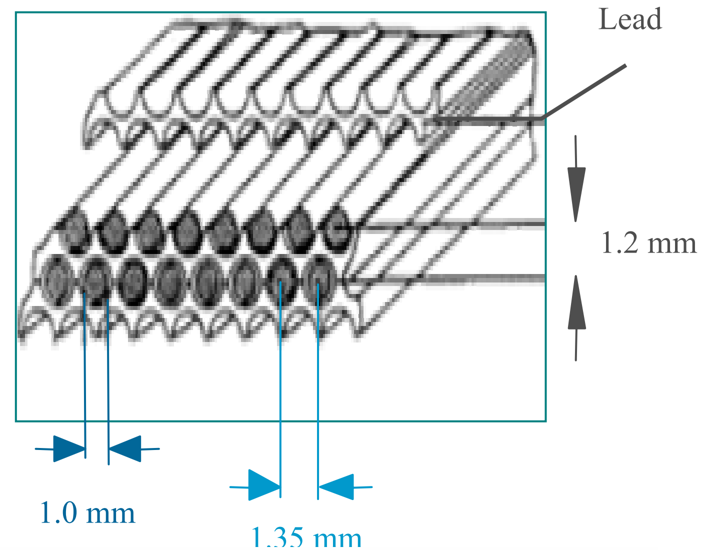
0.52 T
magnetic field

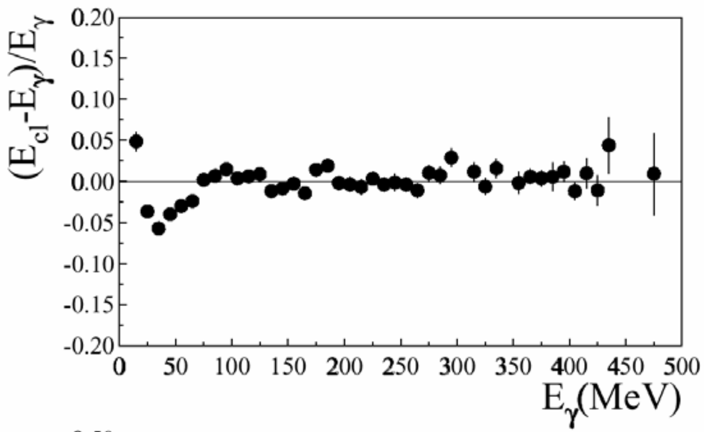


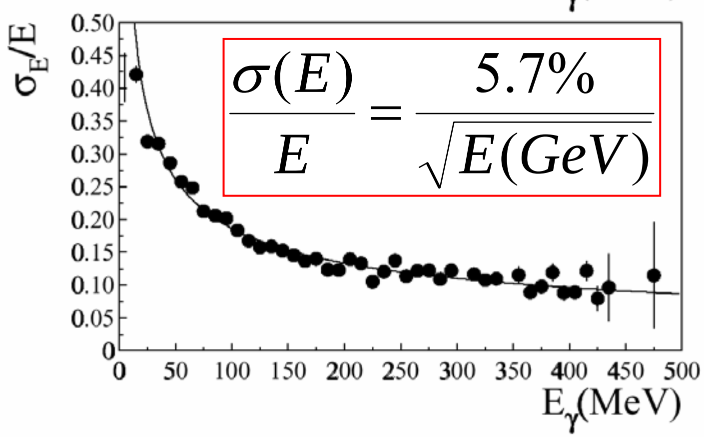
Interaction region:
Instrument quadrupoles,
Al-Be spherical beam pipe

The KLOE Calorimeter

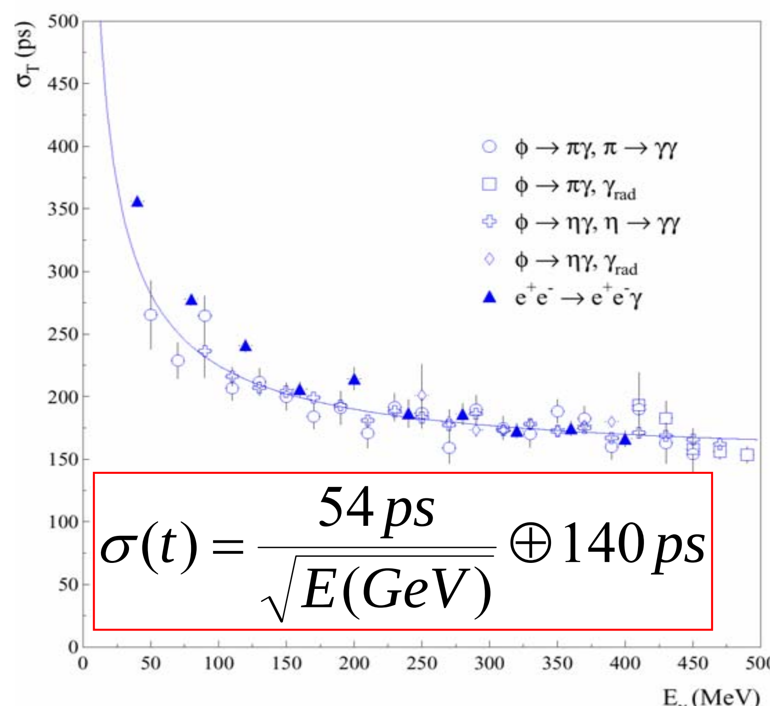
Pb-Sci.Fi. Structure
Light guides + PMT read-out
Energy, Time and impact position measurements.







$$\frac{\sigma(E)}{E} = \frac{5.7\%}{\sqrt{E(GeV)}}$$

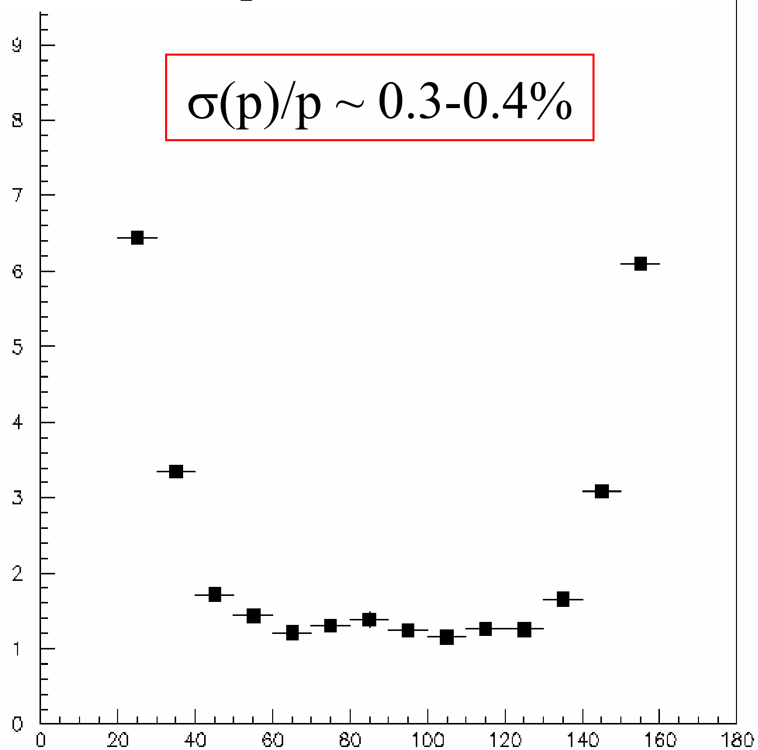


$$\sigma(t) = \frac{54\,ps}{\sqrt{E(GeV)}} \oplus 140\,ps$$

The KLOE Drift Chamber

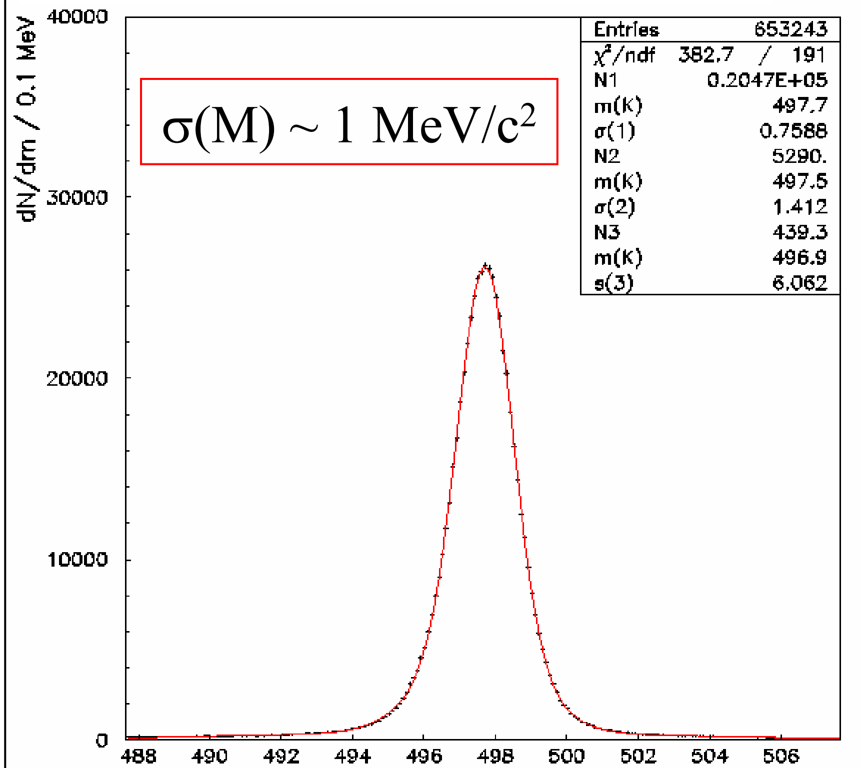
"Light" mechanical structure (carbon fiber) < 0.1 X_0
Gas Mixture = 90% He – 10% Isobut. / All stereo wires → z
Hit position measured with σ(r) ~ 200 μm and σ(z) ~ 2 mm

p(MeV/c) resolution for 510 MeV/c electrons and positrons



Polar angle

M(MeV/c²) resolution for Ks → π⁺π⁻



M(π⁺π⁻) (MeV/c²)

KLOE Data Taking

1.Continuous data taking: no stop at beam injection;

2.Trigger: $\geq$ 2 energy clusters above threshold (50 – 150 MeV)

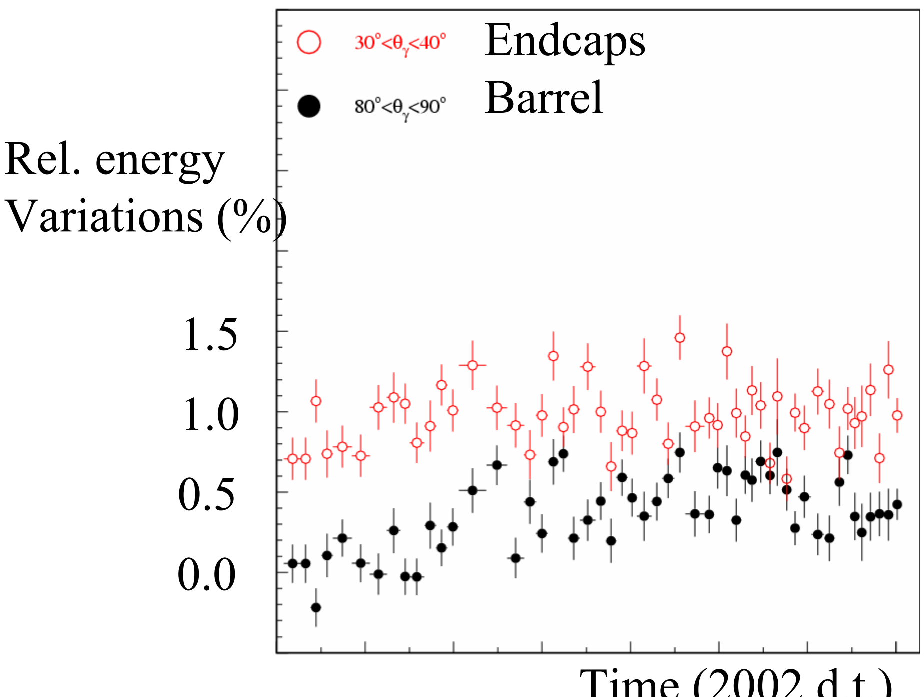
OR > NNN hits in the drift chamber

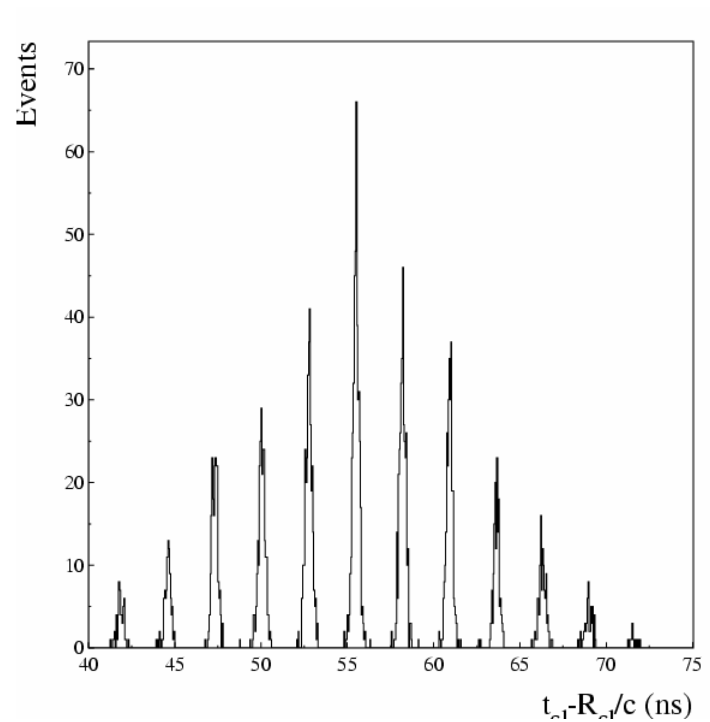
➔ Trigger Rate (kHz) = 1 (physics) + 0.9 (Cosmic rays) + 0.45 (Bckg) = 2.3 kHz

3.On-line calorimeter calibration: (every 200 nb^{-1} ~ 1 h)

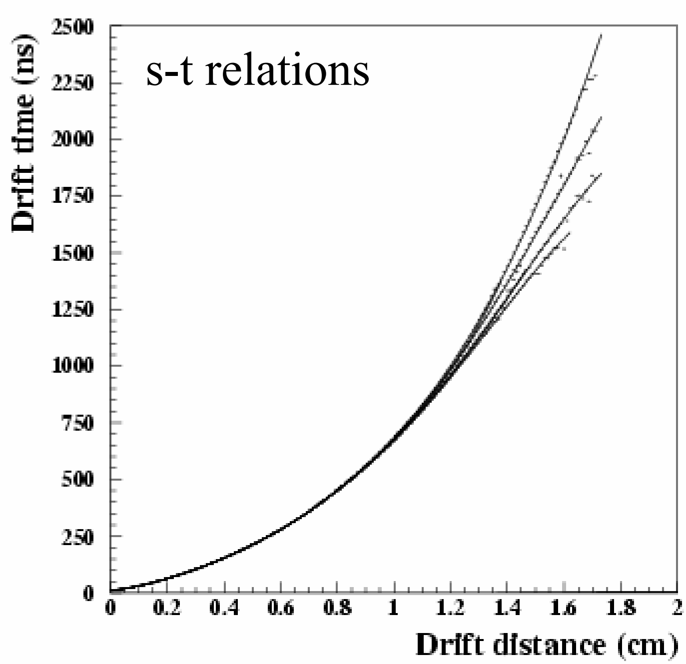
→ Energy (absolute scale from $e^+e^- \rightarrow \gamma\gamma$)

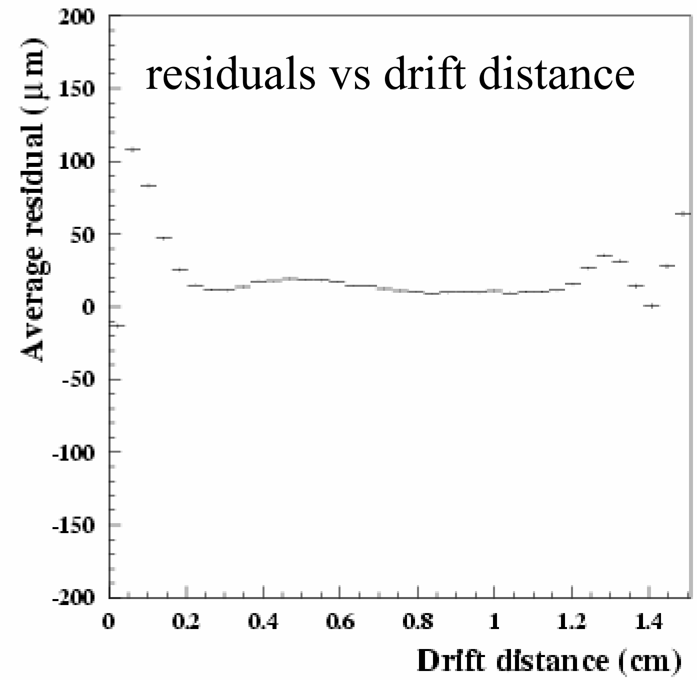
→ Time (absolute scale using DAFNE RF signal (2.715 ns))



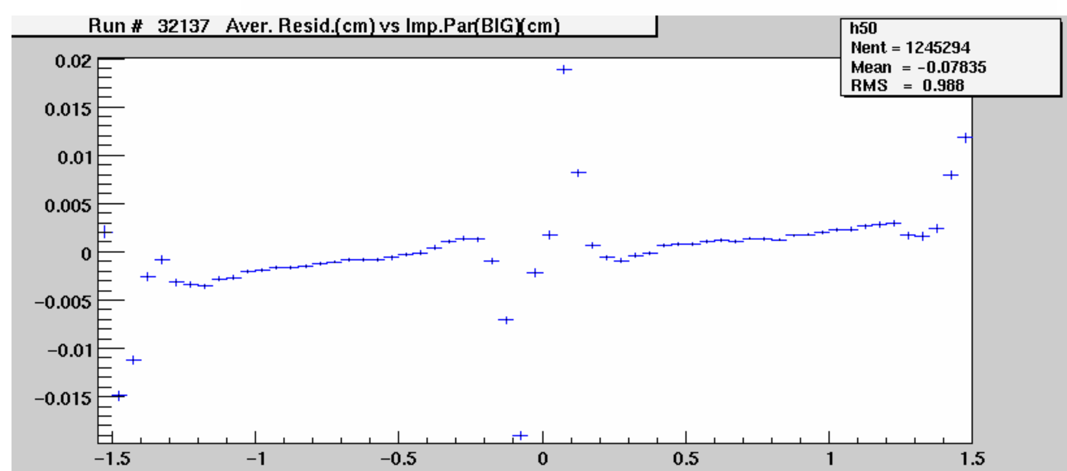


4.Drift Chamber t_0s and space-to-time relations calibration:
Iterative procedure based on cosmic ray runs;
On-line check of residuals using Bhabha and cosmic rays





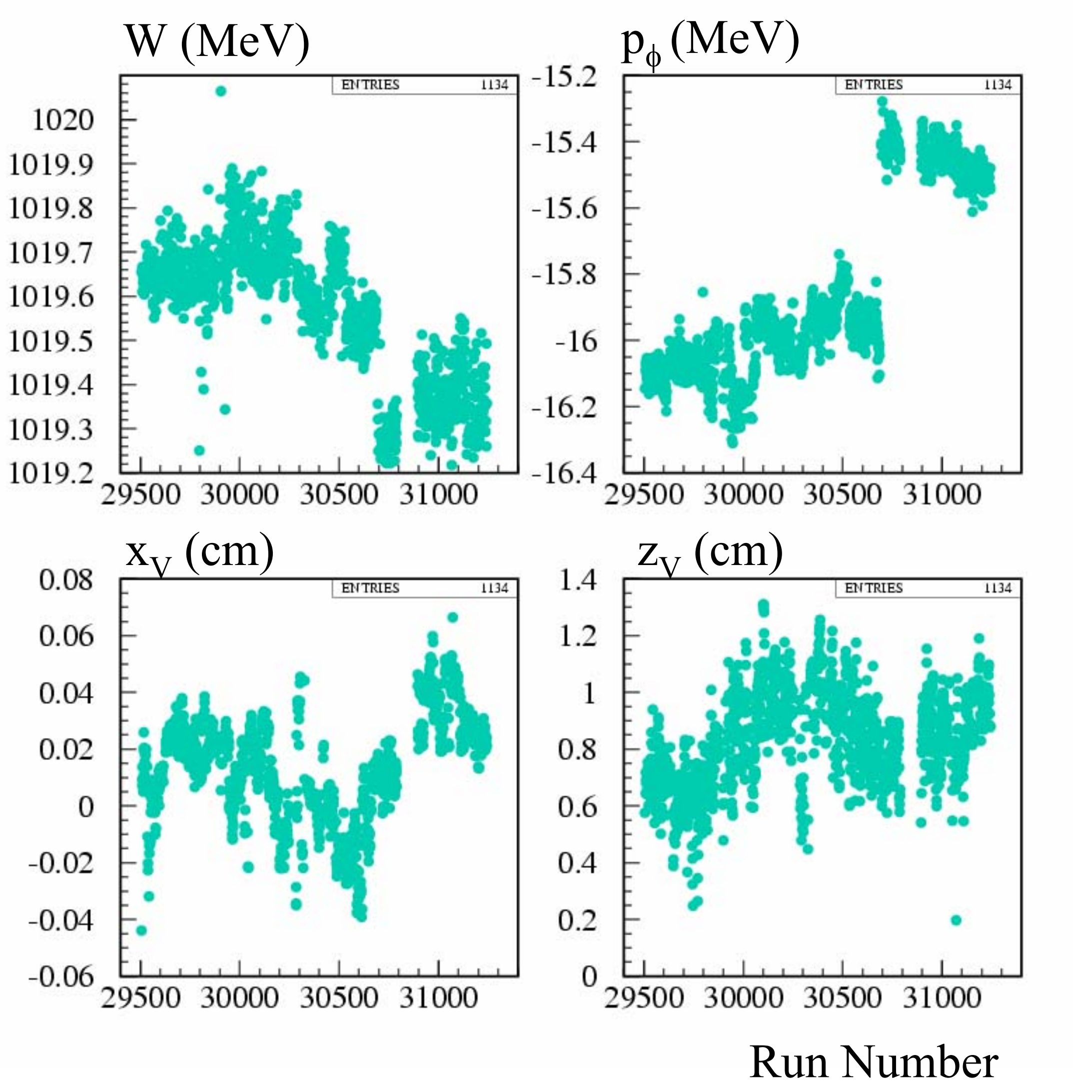
On-line check of residuals
with selected Bhabha events



5. Data quality control

On-line reconstruction → evaluation of relevant quantities run by run:

These variables are used in the data reconstruction procedure and to provide information to the DAFNE team.



$W=\sqrt{s}$ center of mass energy

p_ϕ ϕ momentum (lab. boost)

x_V , y_V, z_V interaction point coordinates

6. Data reconstruction:

End of run: if (calibration_ok) → start Data reconstruction

→ Calorimeter clusters

→ Tracking in Drift Chamber

→ Background rejection (cosmic rays, machine bkg.)

→ Event classification

Big computing effort;

~ 120 CPU used

~ 300 TB tapes (including raw data, DST files and MC events)

4. Overview of KLOE results

(1) Kaon physics

$K_S \to \pi e \nu$	*Phys. Lett.* B535 37 (2002) Preliminary update presented at ICHEP '04
$K_S \to \pi^+\pi^-(\gamma)$ $K_S \to \pi^0\pi^0$	*Phys. Lett.* B538 21 (2002) Update with '01-'02 data in progress
$K_L \to \gamma\gamma / K_L \to 3\pi^0$	*Phys. Lett.* B566 61 (2003)
$K^+ \to \pi^+\pi^0\pi^0$	*Phys. Lett.* B597 2 (2004)
K^0 mass	KLOE Note 181 (http://www.lnf.infn.it/kloe)
Upper limit BR($K_S \to \pi^0\pi^0\pi^0$)	Paper in preparation
$K_L \to \pi\mu\nu, \pi e\nu, \pi^+\pi^-\pi^0, 3\pi^0$	Preliminary results presented at ICHEP '04
V_{us} from K_L and K_S	Preliminary results presented at ICHEP '04
K_L mean life	Preliminary results presented at ICHEP '04
CP violation & interference	In progress
V_{us} from $K^\pm$	In progress

(2) Other results (radiative decays…)

$\phi \to \pi^0\pi^0\gamma$	*Phys. Lett.* B537 21 (2002) Updates in progress
$\phi \to \eta\pi^0\gamma$	*Phys. Lett.* B536 209 (2002) Updates in progress
$\phi \to \eta'\gamma, \eta\gamma$ (mixing angle)	*Phys. Lett.* B541 45 (2002) Updates in progress
$\phi \to \rho\pi, \pi^+\pi^-\pi^0$	*Phys. Lett.* B561 55 (2003)
Upper limit BR($\eta \to 3\gamma$)	*Phys. Lett.* B591 45 (2004)
Hadronic cross section ($0.35 < s < 0.95$ GeV^2)	Paper submitted to *Phys. Lett.* B
Upper limit BR($\eta \to \pi^+\pi^-$)	Paper in preparation
ϕ leptonic width	Paper in preparation
Dalitz plot $\eta \to 3\pi$	Preliminary results presented at ICHEP '04
BR($\eta \to \pi^0\gamma\gamma$)	Preliminary results presented at ICHEP '04
Search for $f_0(980) \to \pi^+\pi^-$	Preliminary results presented at ICHEP '04
Hadronic cross section (down to $2M_\pi^2$=0.08 GeV^2)	In progress

KLOE contributions to 2 *frontier problems* in high energy physics:
(1) Unitarity of the CKM matrix through V_{us} precision measurement
(2) Hadronic corrections to the muon anomaly a_μ

(1) Unitarity Test: $\mathbf{V_{us}}$

At present the most precise test of unitarity of CKM matrix comes from 1st row:

$$|V_{ud}|^2 + |\mathbf{V_{us}}|^2 + |V_{ub}|^2 \sim |V_{ud}|^2 + |\mathbf{V_{us}}|^2 \equiv 1 - \Delta$$

$$\Delta = 0.0042 \pm 0.0019 \text{ (PDG02)}$$

$|V_{ud}|$ is extracted from nuclear β decay (*Czarnecki-Marciano-Sirlin hep-ph/0406324*)

$|V_{us}|$ is extracted from partial widths of kaon semileptonic decays **$\Gamma(K \to \pi l \nu(\gamma))$;**

$$\Gamma(K \to \pi l \nu(\gamma)) \propto |\mathbf{V_{us}}\, f_+^{K\pi}(0)\,|^2\, S_{ew} I_i(\lambda_+, \lambda_0, 0))\,(1 + \delta^i_{em} + \Delta I_i/2)$$

$f_+^{K\pi}(0)$	form factor at 0 momentum transfer: pure theory calculation (χPT, lattice)
$I(\lambda_+, \lambda_0, 0)$	phase space integral, S_{ew} short distance corrections (1.0232)
λ_+, λ_0	slopes (momentum dependence of the vector and scalar form factors)
$\delta^i_{em} + \Delta I_i/2$	long distance radiative corrections for form factor and phase space

KLOE measures all kaon *semileptonics decays* with "tagged kaon beams"

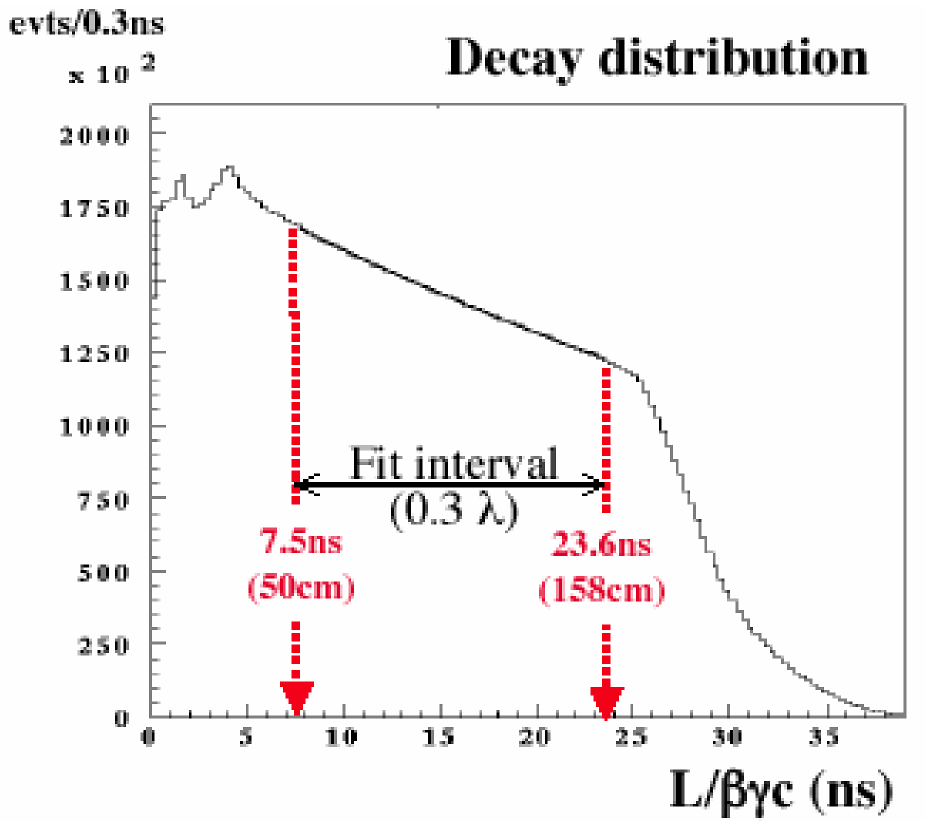
$K_S \rightarrow \pi^{\pm} e\nu$, $\pi^{\pm}\mu\nu$
$K_L \rightarrow \pi^{\pm} e\nu$, $\pi^{\pm}\mu\nu$
$K^{\pm} \rightarrow \pi^{0} e\nu$, $\pi^{0}\mu\nu$

➔ K_L semileptonic decays (preliminary results ICHEP 04)

N_0 tagged K_L $\lambda_L = 3.4$ m
δN_i i=1,4 (4 main K_L decays in δT)
ε_i = efficiency to detect channel i
Prob($\delta T,\tau$) = prob. to decay in δT

$BR_i = \delta N_i / (N_0\, \varepsilon_i\, \mathrm{Prob}(\delta T,\tau))$

(1) τ from fit of time distribution
(2) Impose **$\Sigma_i BR_i = 1 - \varepsilon$** ➔ further equation ➔ determination of τ and single **BR_i**



Results:

BR($K_L \rightarrow \pi e \nu$) = 0.3985 ± 0.0006 ± 0.0035

BR($K_L \rightarrow \pi \mu \nu$) = 0.2702 ± 0.0005 ± 0.0025

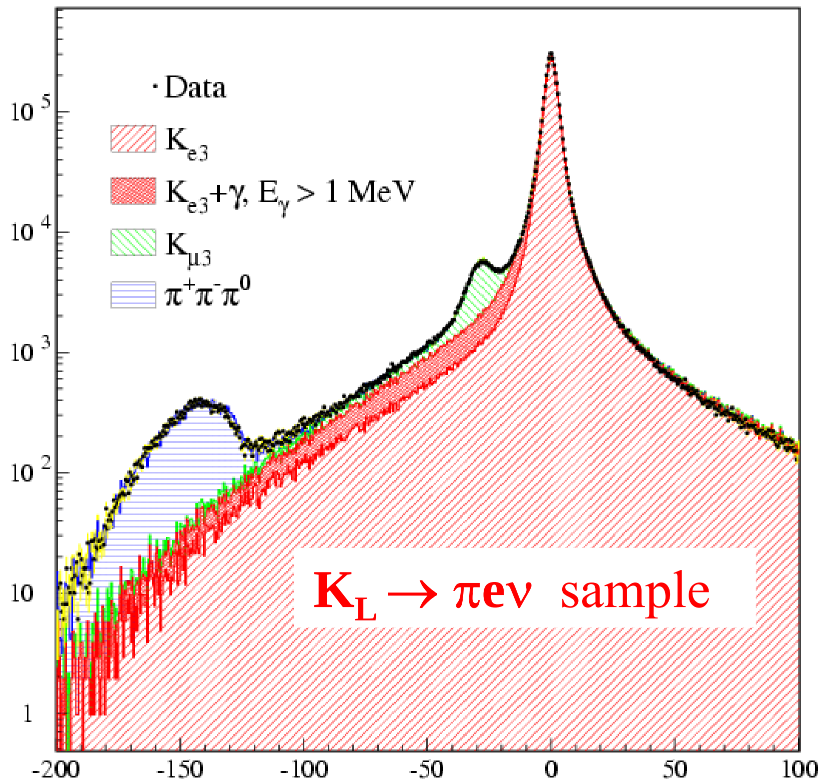
BR($K_L \rightarrow 3\pi^0$) = 0.2010 ± 0.0003 ± 0.0022

BR($K_L \rightarrow \pi^+\pi^-\pi^0$) = 0.1268 ± 0.0004 ± 0.0010

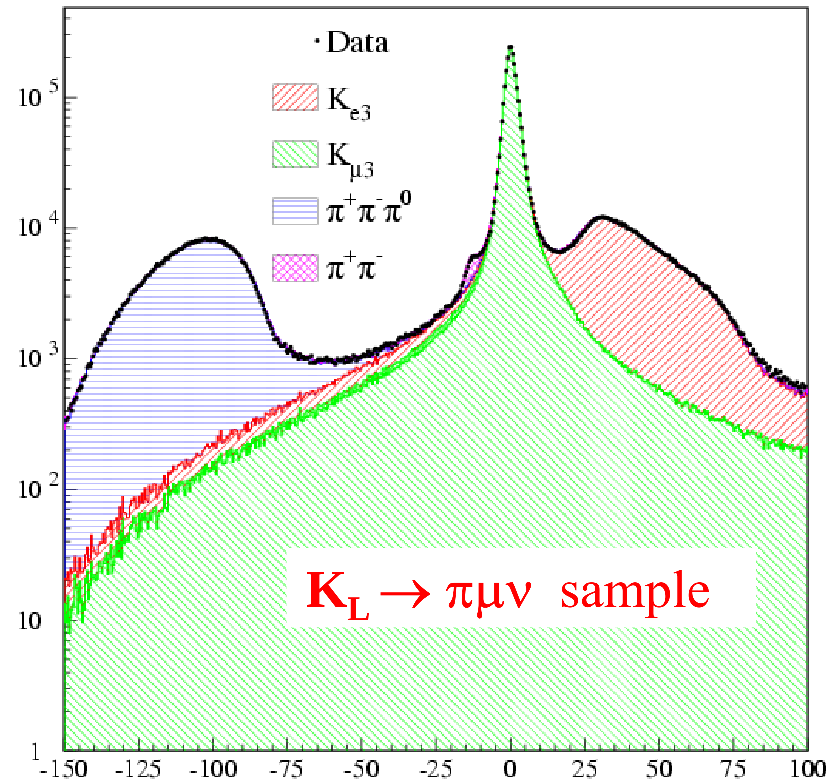
τ = (51.15 ± 0.20 ± 0.40) ns (meth.(1))

τ = (51.35 ± 0.05 ± 0.26) ns (meth.(2))

Consistency check of the method



$P_{miss} - E_{miss}$ in πe or $e\pi$ hyp. (MeV)



$P_{miss} - E_{miss}$ in $\pi\mu$ or $\mu\pi$ hyp. (MeV)

1. K^0_{l3} partial decay widths measured by KLOE $\Gamma(e3,\mu3) = BR(e3,\mu3) / \tau$

2. $f_+^{K\pi}(0)$ from Leutwyler-Roos 0.961(8) confirmed by Becirevic et al. (lattice+CHPT) 0.961(9)

3. quadratic parametrization of form factors (+ slopes from **kTeV** measurements)

$$f_i(t) - f_i(0)\left[1 + \lambda_i \frac{t}{m^2_{\pi-}} + \frac{\lambda'_i}{2}\frac{t^2}{m^4_{\pi+}}\right]$$

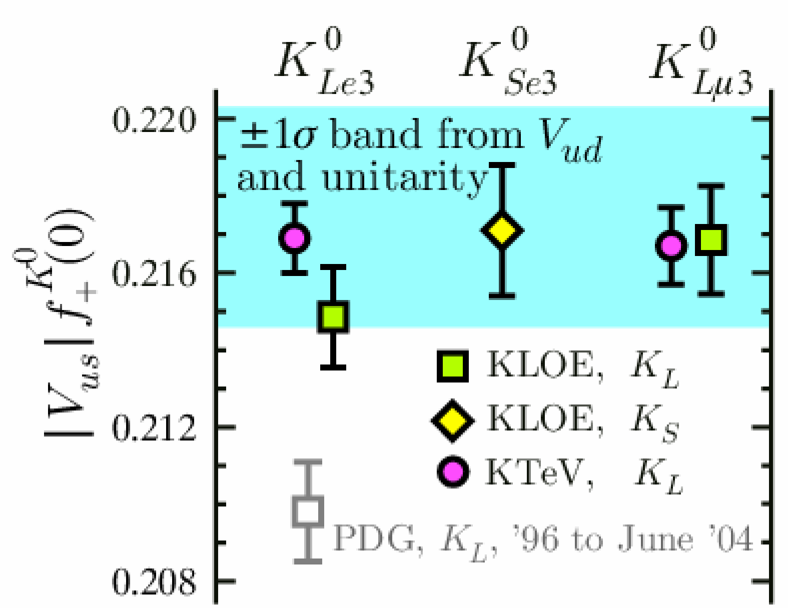
$$\lambda_+ = 0.0206 \pm 0.0018$$
$$\lambda'_+ = 0.0032 \pm 0.0007$$
$$\lambda_0 = 0.0137 \pm 0.0013$$

$$\mathbf{|V_{us}| = 0.2248 \pm 0.0015_{(exp.)} \pm 0.0020_{(the.)}}$$ preliminary

Comparison with Unitarity:

$|V_{us}|\, f_+^K(0)$

New results indicate no deviations from CKM unitarity

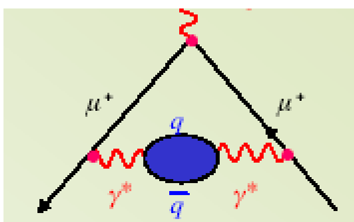


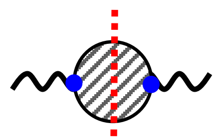
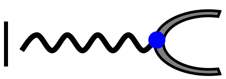
(2) Hadronic corrections to g-2

Precision test of the Standard Model:

$$a_\mu^{\text{exp}} \text{ vs. } a_\mu^{\text{th}} = a_\mu^{\text{QED}} + a_\mu^{\text{weak}} + a_\mu^{\text{had}}$$

$$a_\mu^{\text{QED}} = (11\ 658\ 470.35 \pm 0.28) \times 10^{-10}$$
$$a_\mu^{\text{weak}} = (15.4 \pm 0.2) \times 10^{-10}$$
$$A_\mu^{\text{had}} = (693 \pm 7) \times 10^{-10}$$

$a_\mu^{\text{had,LO}} =$ 

Im[] $\propto$ |  hadrons $|^2$

$$a_\mu^{had,lo} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} \sigma_{e^+e^- \to hadr}(s) K(s)\, ds$$

$K(s) \sim 1/s$ (kernel function)

The $e^+e^- \to \pi^+\pi^-$ channel accounts for ~72% of the contribution

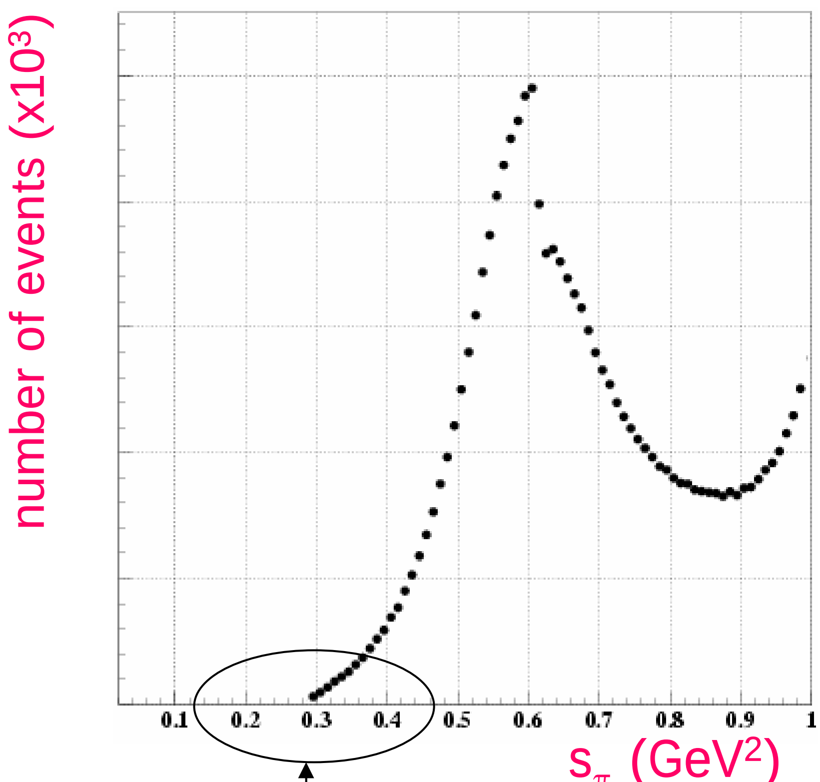
both to a_μ^{had} and to $\sigma^2(a_\mu^{had})$

Radiative Return Method: select $\pi^+\pi^-\gamma$ *events with* $\theta_\gamma < 15^o$

Enhancement of ISR vs. FSR

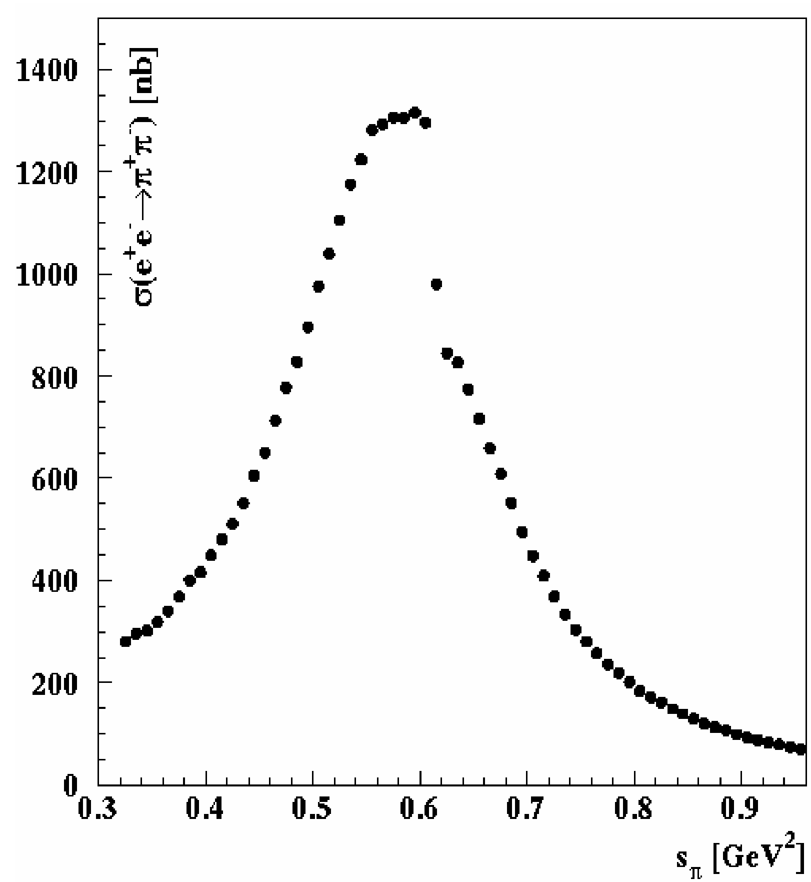
Effective threshold in S_π

1 550 000 events / 141 pb^{-1}



Our cuts select events with $\sqrt{s_\pi}$ >550 MeV

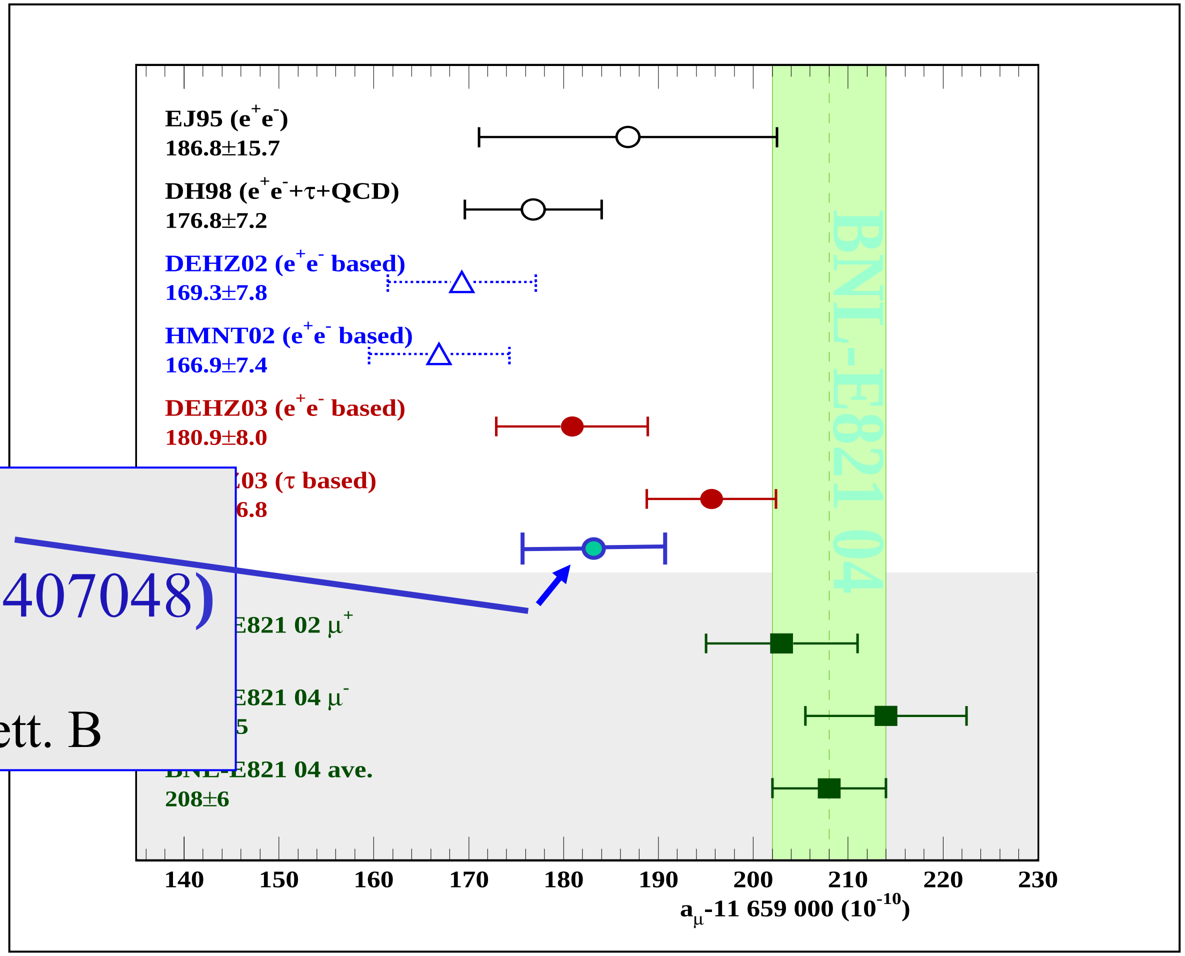
H(Q²) ⇒



Integral… ➔ $a_\mu^{\mathbf{had}}$

KLOE (375.6 ± 0.8$_{stat}$ ± 4.8$_{syst+theo}$) 10^{-10} 1.3% *Error*

CMD-2 (378.6 ± 2.7$_{stat}$ ± 2.3$_{syst+theo}$) 10^{-10} 0.9% *Error*

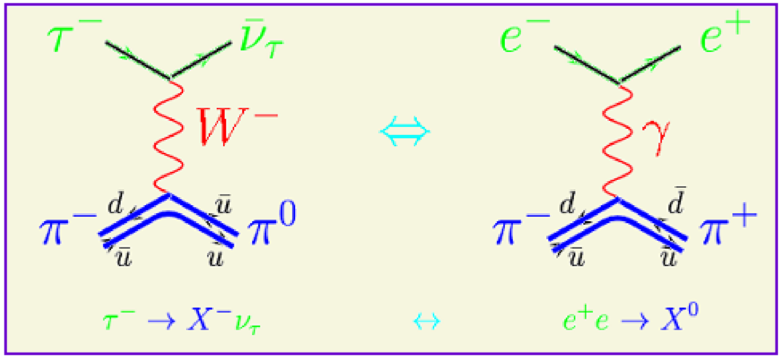


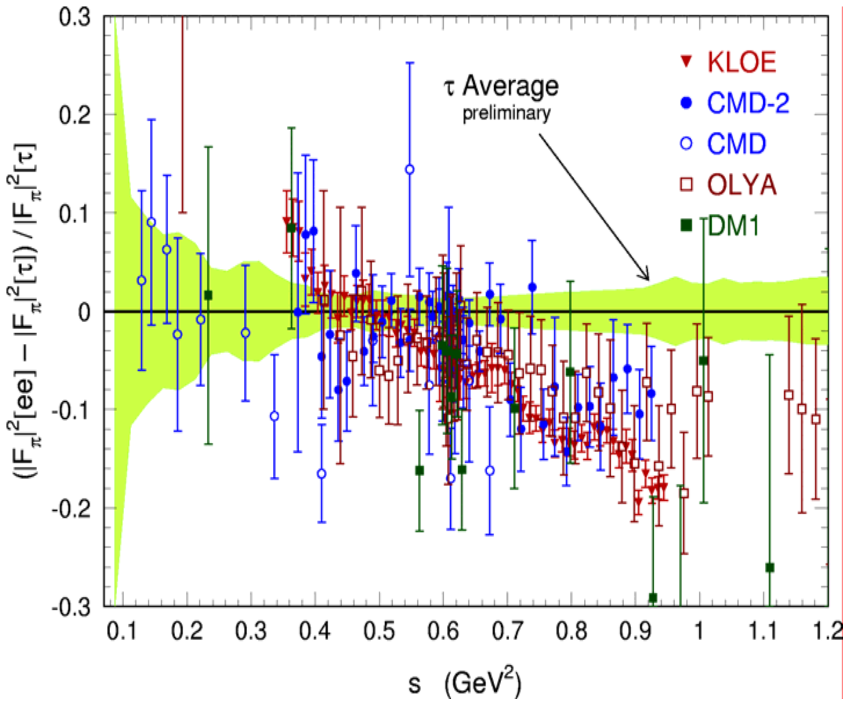
KLOE
(hep-ex/0407048)
Submitted
to Phys. Lett. B

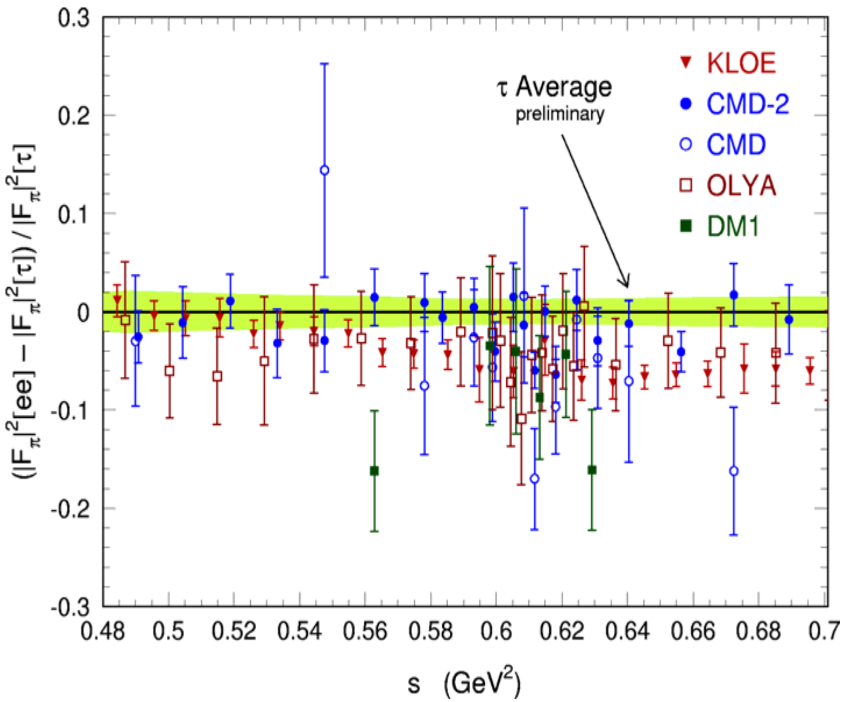
KLOE confirms a deviation of 2.7σ (according to an updated analysis of DHEZ) btw. theory and experiment for $(g-2)_\mu$!

KLOE data are relevant because they confirm e^+e^- - τ data discrepancy

g_μ - 2: e^+e^- Data vs τ Data







KLOE agrees with CMD-2: τ data disagrees with e^+e^-

5. Conclusions and outlook

KLOE operation @ 4th period of data taking.
Several results reached: among the latest

→ V_{us} determination
→ hadronic corrections to g-2

DAFNE program: KLOE run until L(int) = 2 fb^{-1}

→ with present luminosity it means ~ 10 months data taking (realistic estimate)
→ 6×10^9 ϕ decays
→ 8×10^7 η decays
→ 4×10^5 η' decays