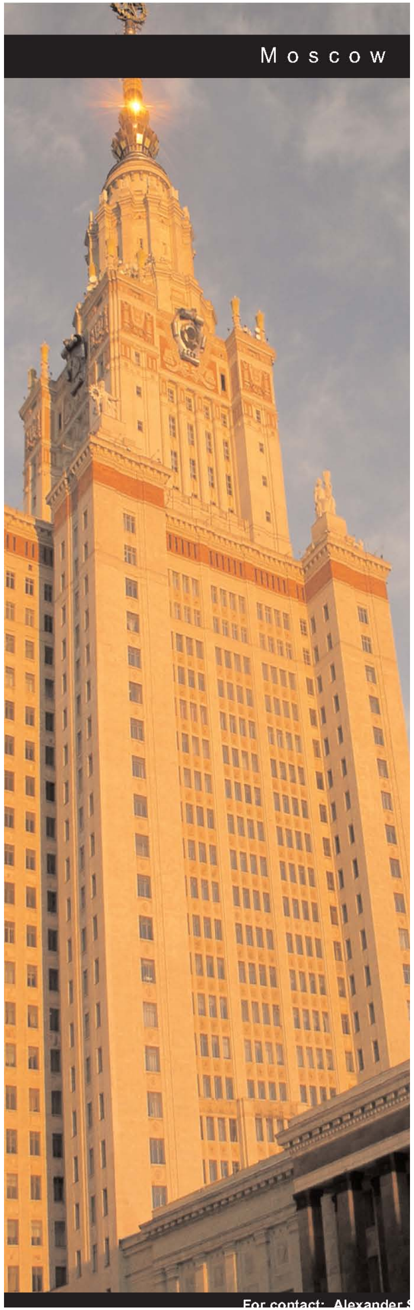

Recent results from KLOE experiment

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On behalf of the KLOE Collaboration

XIV Lomonosov Conference
Moscow State University
18-25 August 2009

Outline

- KLOE experiment

- Kaon physics
  - V_{us}
  - Quantum interference
  - $K_{e2}/K_{\mu 2}$

- Hadron physics
  - $\eta \rightarrow \pi\pi ee/eeee$
  - Gluonium
  - Scalars
  - Cross sections

- Conclusion and perspective

DAΦ NE Facility at Frascati

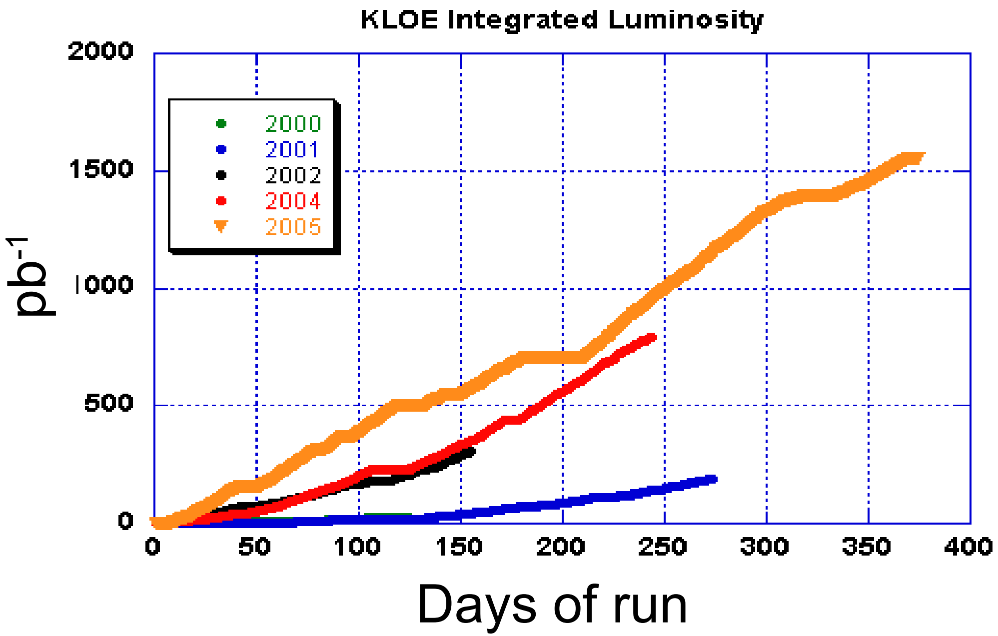
electron-positron collider

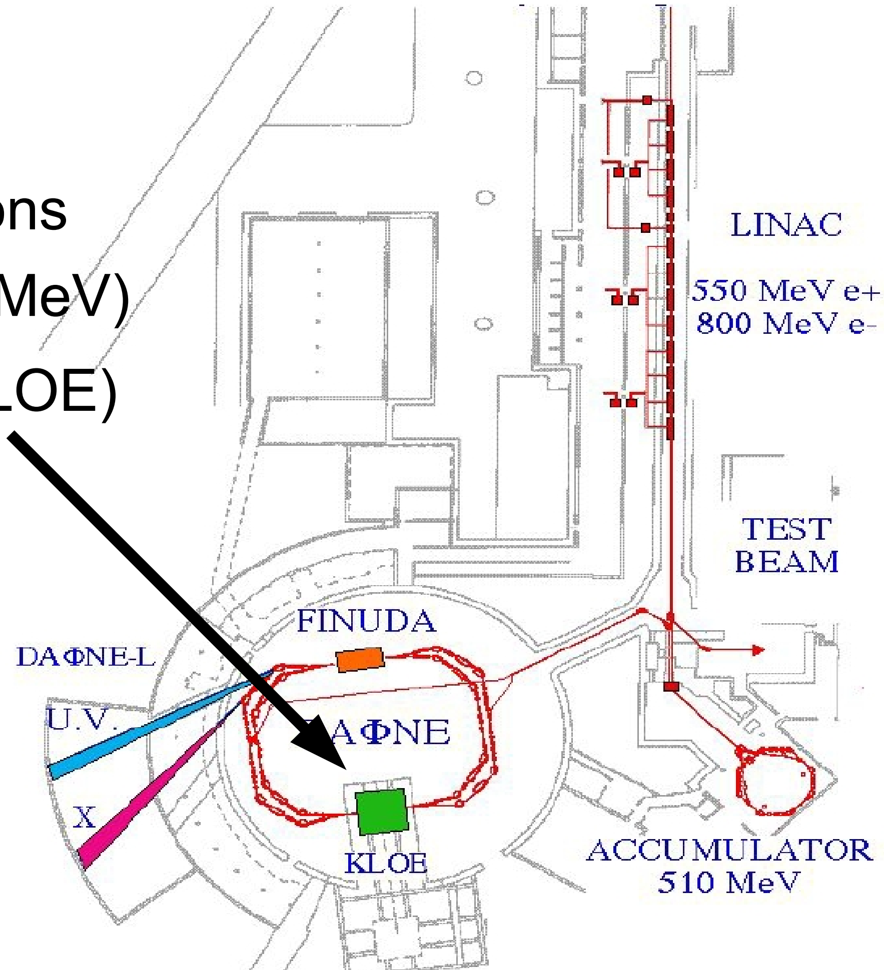
$\sqrt{s} = m_\phi = 1.019$ GeV $\sigma(\phi) \approx 3\ \mu b$

2 rings to minimize beam-beam interactions

2x12.5 mrad crossing angle ($p_x(\phi)$ ~12.5 MeV)

2 interaction regions (one reserved for KLOE)





Double Annular ring For Nice Experiments

The KLOE detector

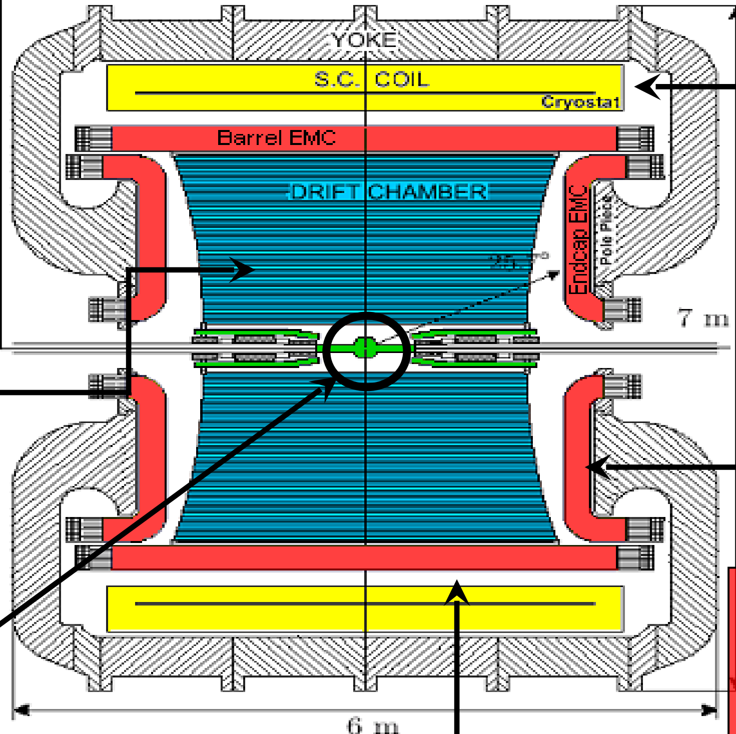
Drift Chamber

$\sigma_p/p \cong 0.4$ %

(tracks with $\theta > 45°$)

$\sigma_x^{hit} \cong$ 150 mm (xy), 2 mm (z)

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



SC Magnet

B = 0.52 T

End Cap

Calorimeter e.m.

Both side read-out (PM)

~4π solid angle coverage

$\sigma_E/E \cong$ 5.7% /√E(GeV)

$\sigma_t \cong$ 54 ps /√E(GeV) ⊕ 50 ps

Barrel

Interaction point (IP)

Sphere Al-Be (Ø 10 cm)

V_{us}

Vus, CKM matrix, gauge universality

Standard-model coupling of quarks and leptons to W:

$$\frac{g}{\sqrt{2}} W_\alpha^+ \left(\overline{\mathbf{U}}_L \mathbf{V}_{\rm CKM} \gamma^\alpha \mathbf{D}_L + \overline{e}_L \gamma^\alpha \nu_{e\,L} + \overline{\mu}_L \gamma^\alpha \nu_{\mu\,L} + \overline{\tau}_L \gamma^\alpha \nu_{\tau\,L} \right) + \text{h.c.}$$

↑ *Single gauge coupling*

↑ *Unitary matrix*

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

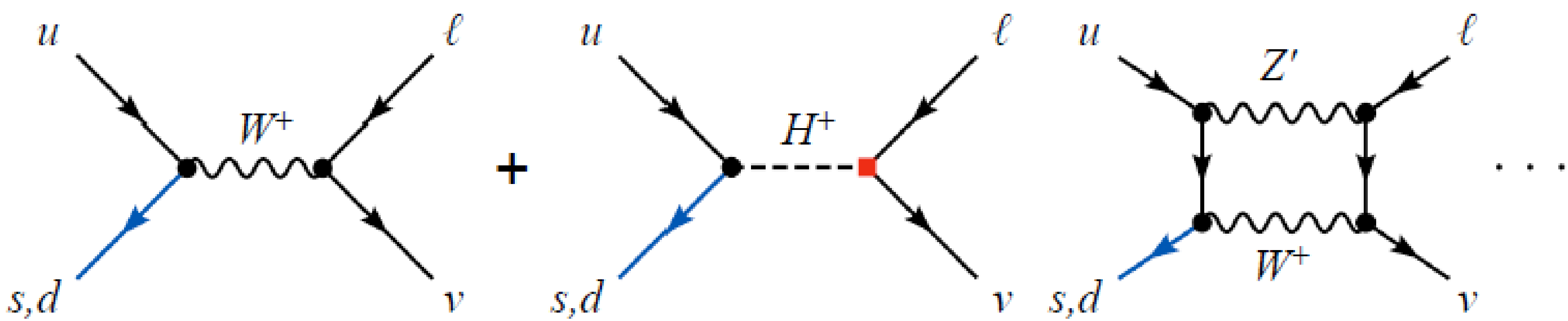
$|V_{ub}|^2 \approx 2\times10^{-5}$

Most precise test of CKM unitarity

Universality: Is G_F from μ decay equal to G_F from π, K, nuclear β decay?

$$G_\mu^2 = (g_\mu g_e)^2 / M_W^4 \quad \stackrel{?}{=} \quad G_{\rm CKM}^2 = (g_q g_\ell)^2 \left(|V_{ud}|^2 + |V_{us}|^2\right) / M_W^4$$

Physics beyond the Standard Model can break gauge universality:



V_{us} from K_{l3}

$$\Gamma(K_{l3(\gamma)}) = \frac{C_K^2 G_F^2 M_K^5}{192\pi^3} S_{EW} |V_{us}|^2 |f_+^{K^0\pi^-}(0)|^2 \times I_{Kl}(\{\lambda\}_{Kl}) (1 + 2\Delta_K^{SU(2)} + 2\Delta_{Kl}^{EM})$$

with $K \in \{K^+, K^0\}$; $l \in \{e, \mu\}$, and:

C_K^2 1/2 for K^+, 1 for K^0

Inputs from theory:

S_{EW} Universal short distance EW correction (1.0232)

$f_+^{K^0\pi^-}(0)$ Hadronic matrix element at zero momentum transfer (t=0)

$\Delta_K^{SU(2)}$ Form factor correction for strong SU(2) breaking

Δ_{Kl}^{EM} Long distance EM effects

Inputs from experiment:

$\Gamma(K_{l3(\gamma)})$ **Branching ratios** with well determined treatment of radiative decays; **lifetimes**

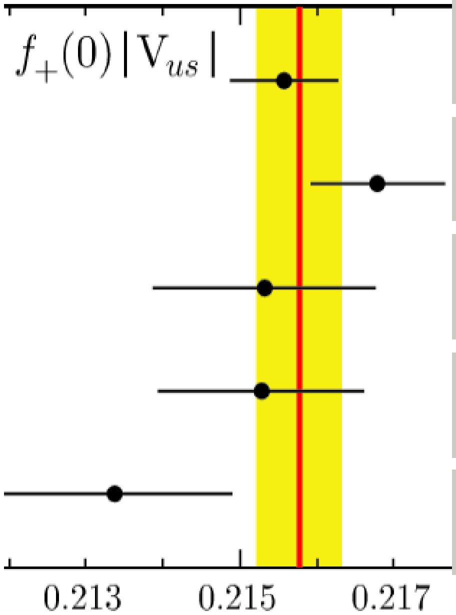
$I_{Kl}(\lambda)$ Phase space integral: λs parameterize form factor dependence on t :

K_{e3} : *only* λ_+ (or λ_+' λ_+'')

$K_{\mu3}$: *need* λ_+ *and* λ_0

$f_+(0)|V_{us}|$ à la KLOE

All KLOE inputs but K_S lifetime



		err %
$K_L e3$	0.2155(7)	0.3
$K_L \mu 3$	0.2167(9)	0.4
$K_S e3$	0.2152(14)	0.7
$K^{\pm} e3$	0.2152(13)	0.6
$K^{\pm} \mu 3$	0.2132(15)	0.7

Comparing Ke3 with Kμ3
We can test lepton universality with kaons

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

JHEP04(2008)059

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

JHEP04(2008)059

$f_+(0)|V_{us}| = 0.2157(6)$ $\chi^2_{/ndof} = 7/4$ (13%)

$|V_{us}| = 0.2237(13) \Rightarrow 1-|V_{us}|^2-|V_{ud}|^2 = 9(8)\times 10^{-4}$

$f_+(0)=0.964(5)$ — **PRL 100 (2008)**

$|V_{ud}| = 0.97418(26)$ — **PRC 77 (2008)**

Constraining CKM unitarity

$|V_{us}/V_{ud}| = 0.2323(15)$

$BR(K^{\pm} \to \mu^{\pm}\nu) = 0.6366(17)$

$f_K/f_\pi = 1.189(7)$

PLB 632 (2006)

PRL 100 (2008)

$|V_{us}| = 0.2237(13)$ from Kl3 decays

$|V_{ud}| = 0.97418(26)$

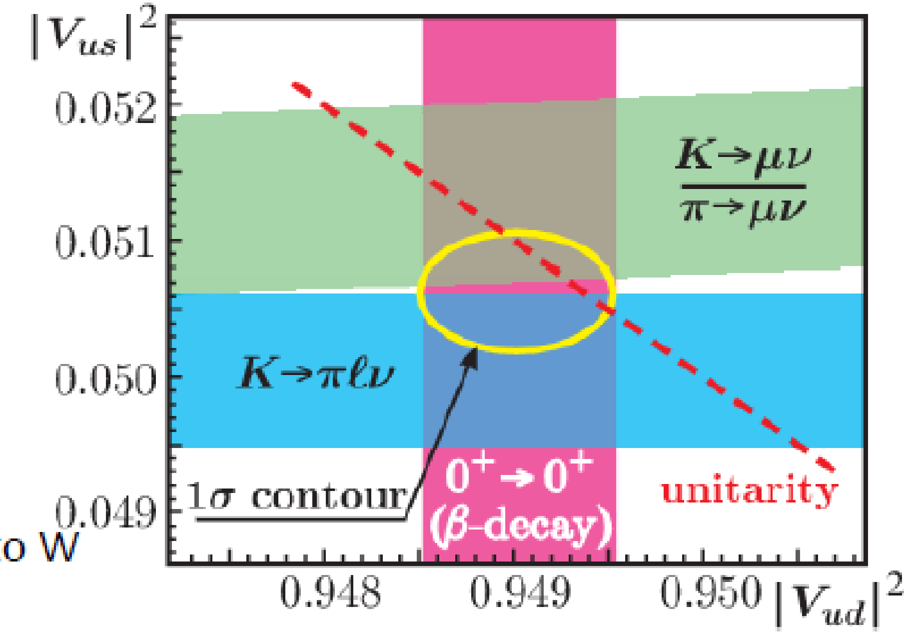
- Fit to $|V_{ud}|^2$, $|V_{us}|^2$ and $|V_{us}/V_{ud}|^2$

JHEP 04 (2008)

$|V_{ud}|^2 = 0.9490(5)$
$|V_{us}|^2 = 0.0506(4)$
$\chi^2 = 2.3/1$ (13%)

- Agreement with unitarity

$1-V_{ud}^2-V_{us}^2 = 4(7)\times10^{-4}$ @0.6σ



- Universality of lepton and quark weak coupling to W

$G_F = 1.166371(6)\times10^{-5}$ GeV^{-2}

$G_{CKM} = 1.16604(40)\times10^{-5}$ GeV^{-2}

$G_{ew} = 1.1655(12)\times10^{-5}$ GeV^{-2}

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

from ew precision tests

Sensitivity to new physics: an example

Using the determination of V_{us} from K_{l3} and V_{ud} from superallowed β decay and the ratio $K_{\mu 2}/\pi_{\mu 2}$ we can explore new physics model.

The observable

$$R_{\ell 23} = \left| \frac{V_{us}(K_{\mu 2})}{V_{us}(K_{\ell 3})} \times \frac{V_{ud}(0^+ \to 0^+)}{V_{ud}(\pi_{\mu 2})} \right|$$

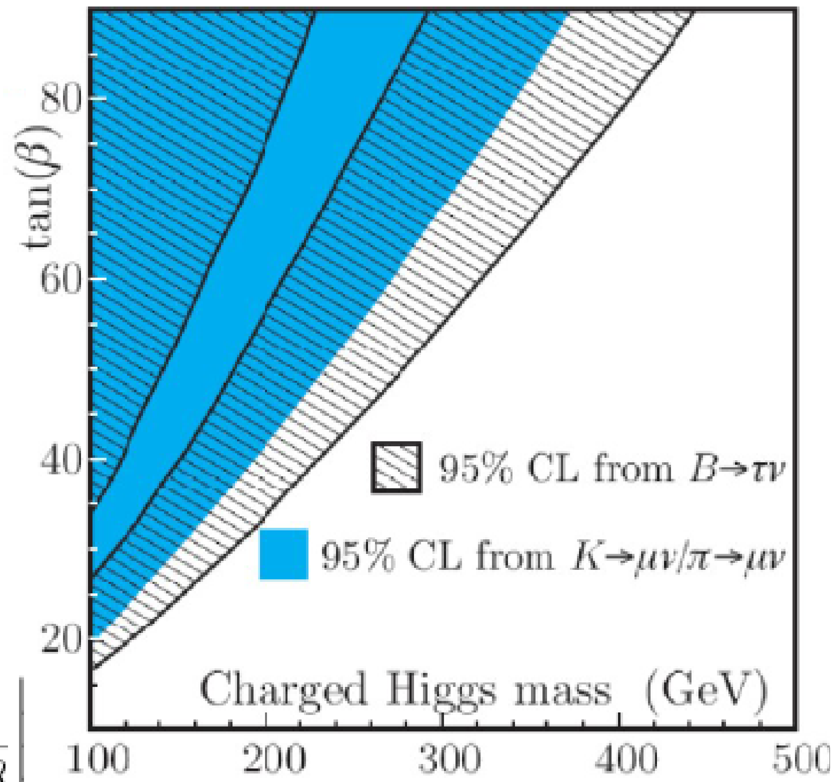
we get:

- R_{l23} **= 1.008(8)**

(unitarity for K_{l3} and β-decays is used)

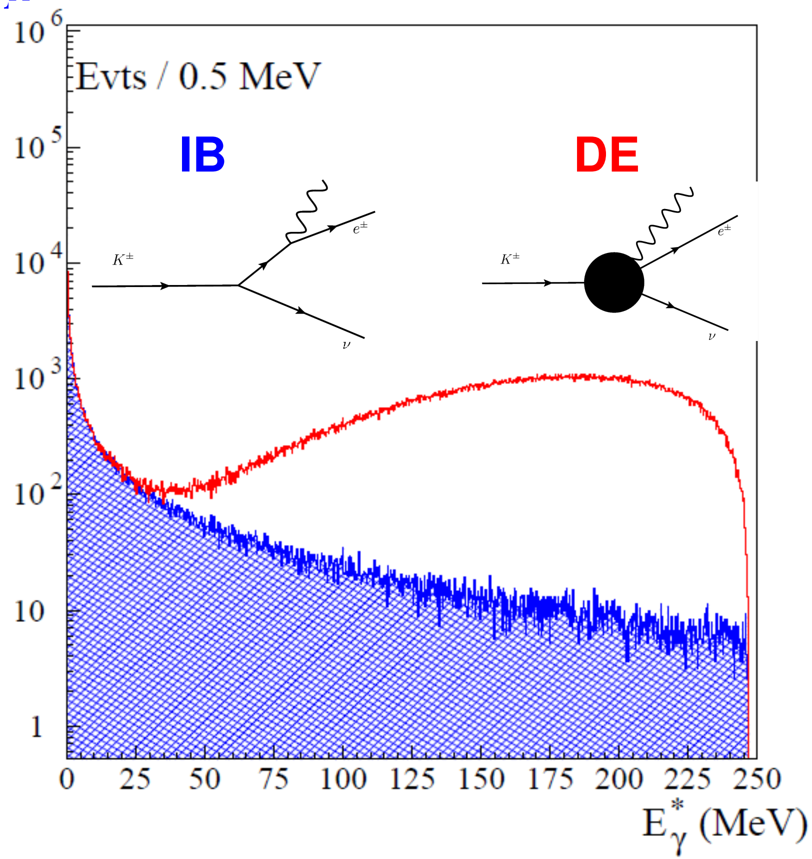
R_{l23} sensitivity to $H^{\pm}$ exchange

$$R_{\ell 23} = \left| 1 - \frac{m^2_{K^+}}{m^2_{H^+}} \left(1 - \frac{m^2_{\pi^+}}{m^2_{K^+}} \right) \frac{\tan^2 \beta}{1 + \epsilon_0 \tan \beta} \right|$$



$K_{e2}/K_{\mu 2}$

R_K: LFV beyond SM



Very high precision prediction in the SM (no hadronic uncertainties)

$R_K^{SM} = 2.477(1)\times10^{-5}$

[JHEP10(2007)005]

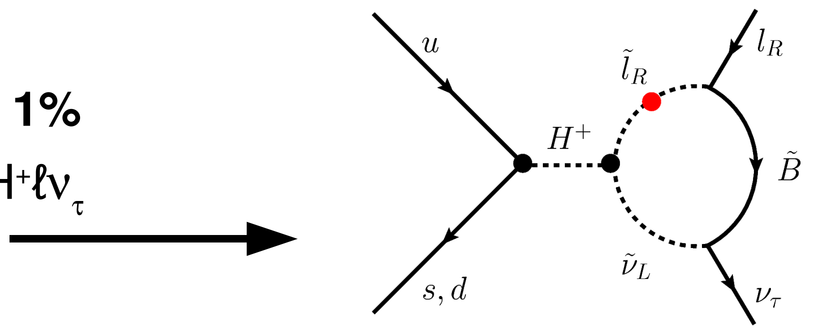
***In SM o*nly IB included**

$R_K^{SM} = (K_{e2}(\gamma_{IB}))/ (K_{\mu 2}(\gamma_{IB}))$

LFV in the MSSM would enhance R_K up to 1%

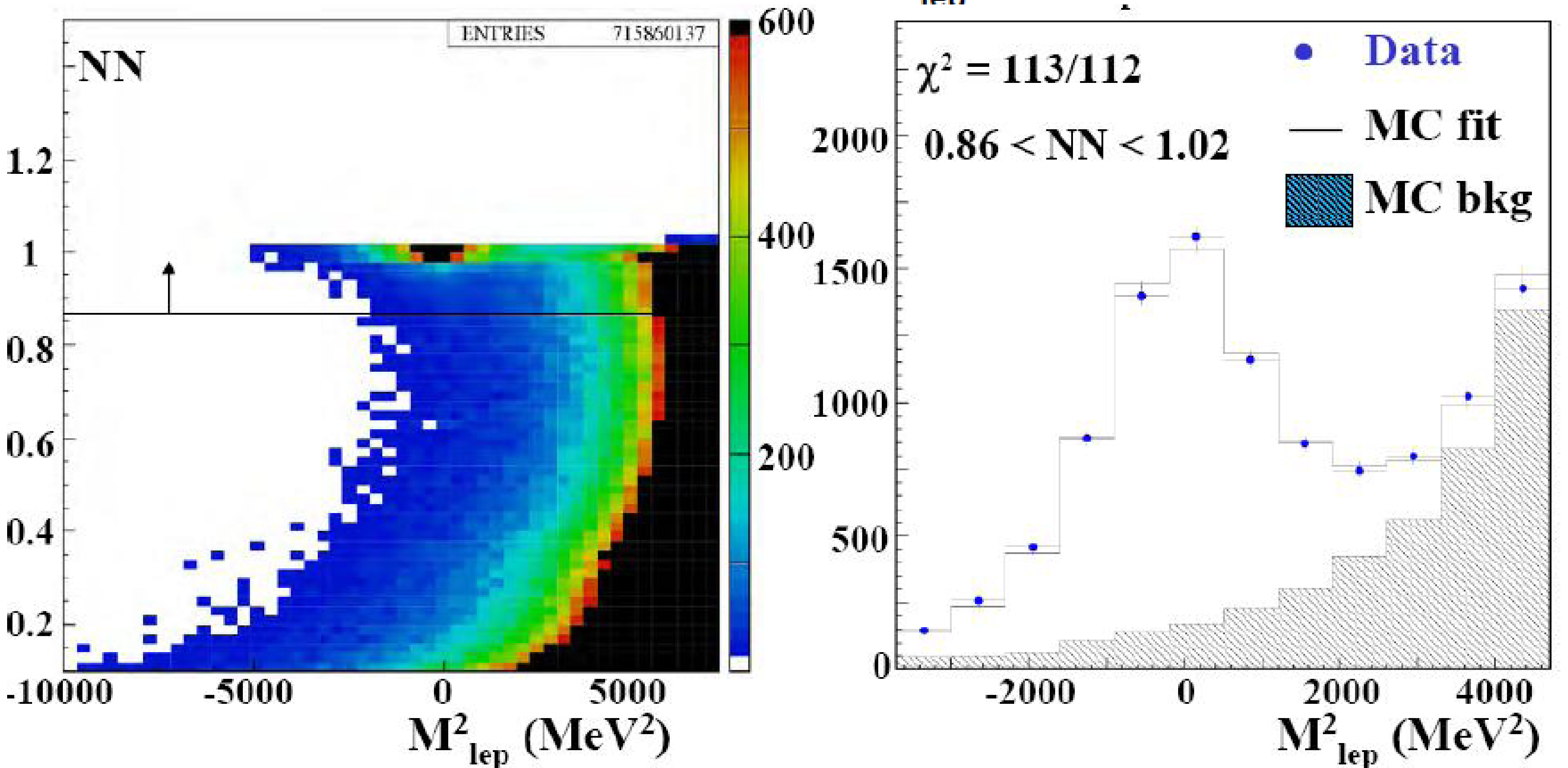
LFV appears at 1-loop level via an effective $H^+\ell\nu_\tau$ Yukawa interaction dominated by $e\nu_\tau$

[PRD74(2006)011701]



Signal counting

- Ke2 counts from two-dimensional binned likelihood fit in the NN- M^2_{lep} plane with 0.86 < NN < 1.02 and -3700 < M^2_{lep} < 6100



Using the whole statistics: NKe2(e^+) = 7064(102) , NKe2(e^-) = 6750(101)

- Kμ2 counting from 1-dimensional fit of M^2_{lep} distribution without PID

R_K final result

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

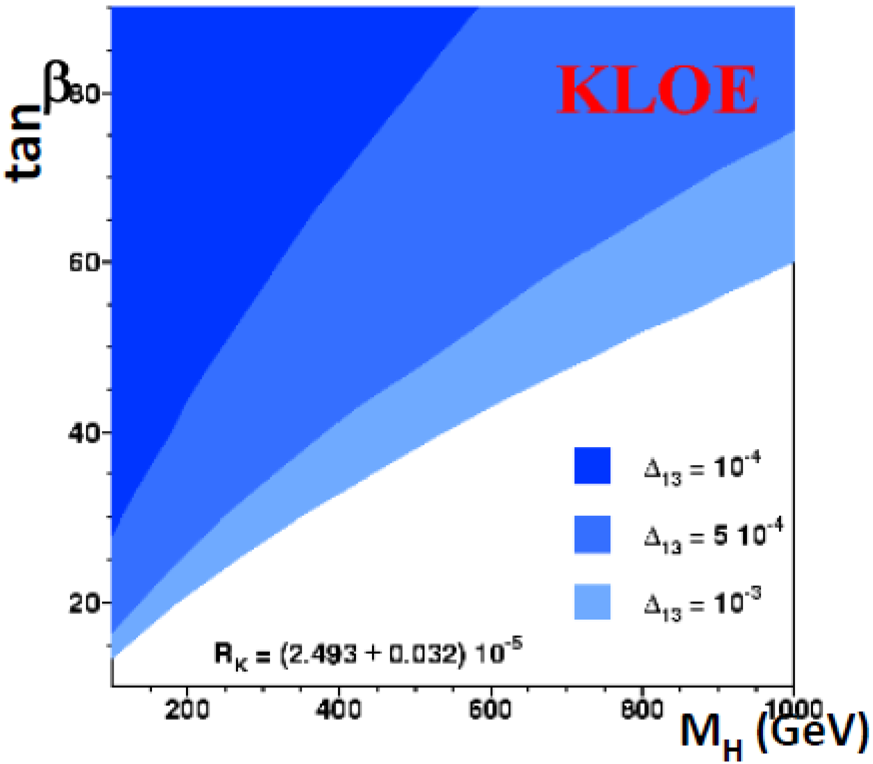
1.0% 0.8%

$R_K^{SM} = (2.477 \pm 0.001)\ 10^{-5}$

Systematic errors %	stat	syst
Reconstruction	0.4	0.4
Trigger efficiency	0.4	-
Background sub	-	0.3
Ke2(DE) comp.	0.2	-
Clustering	0.2	
Total	0.6	0.5

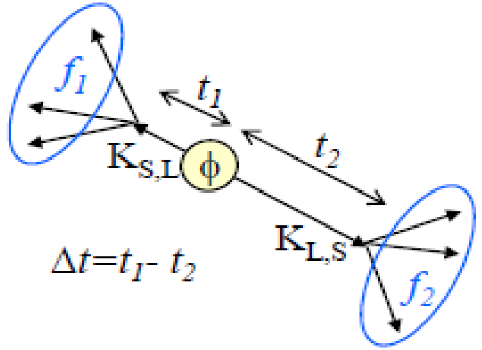
- Main contribution to systematic uncertainty from control-sample statistics (0.6%)

Sensitivity shown as 95%-CL excluded regions in the tanβ - M_H plane, for fixed values of the 1-3 slepton-mass matrix element, $\Delta_{13} = 10^{-3}, 0.5\times10^{-3}, 10^{-4}$



Kaon interferometry

Kaon interferometry: basic principles

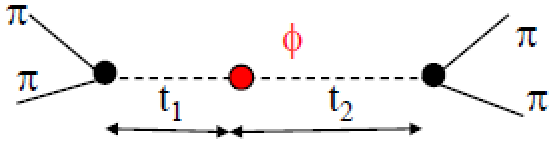


$$|i\rangle = \frac{1}{\sqrt{2}}\left[\left|K^0(\vec{p})\right\rangle\left|\bar{K}^0(-\vec{p})\right\rangle - \left|\bar{K}^0(\vec{p})\right\rangle\left|K^0(-\vec{p})\right\rangle\right]$$
$$= \frac{N}{\sqrt{2}}\left[\left|K_S(\vec{p})\right\rangle\left|K_L(-\vec{p})\right\rangle - \left|K_L(\vec{p})\right\rangle\left|K_S(-\vec{p})\right\rangle\right]$$

$$I(f_1, f_2; \Delta t) = \frac{\Gamma_S^1 \Gamma_S^2}{2\Gamma} e^{-\Gamma|\Delta t|}\left[|\eta_1|^2 e^{\frac{\Delta\Gamma}{2}\Delta t} + |\eta_2|^2 e^{-\frac{\Delta\Gamma}{2}\Delta t} - 2\Re e\left(\eta_1 \eta_2 e^{-i\Delta m \Delta t}\right)\right]$$

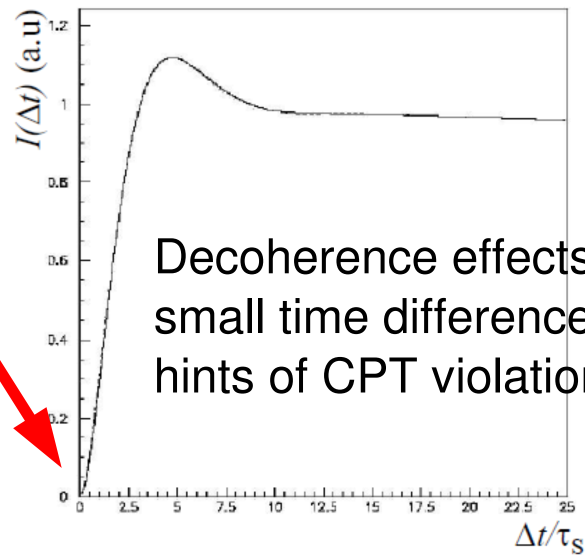
Assuming same final state: $\pi^+\pi^-$

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



EPR correlation:

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



Decoherence effects at small time difference are hints of CPT violation.

Decoherence parameter

- Analysed data:
  L=1.5 fb^{-1} (2004-05 data)
- Fit including Δt resolution and efficiency effects + regeneration
- Γ_S, Γ_L, Δm fixed from PDG

KLOE FINAL:

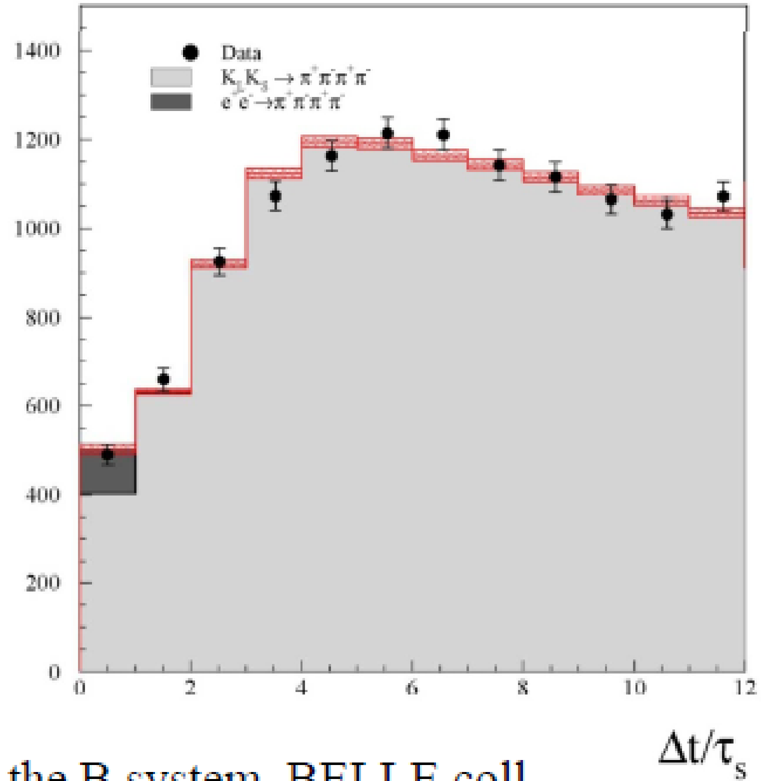
$$\zeta_{0\bar{0}} = (1.4 \pm 9.5_{STAT} \pm 3.8_{SYST}) \times 10^{-7}$$

as CP viol. $O(|\eta_{+-}|^2) \sim 10^{-6}$
=> high sensitivity to $\zeta_{0\bar{0}}$

- Improvement x 2 wrt published KLOE measurement (PLB 642(2006) 315)

- From CPLEAR data $(p\bar{p})_{REST} \to K^0\overline{K}^0$ Bertlmann et al. obtain (PR D60 (1999) 114032):

$$\zeta_{0\bar{0}} = 0.4 \pm 0.7$$



- In the B system, BELLE coll. (PRL 99 (2007) 131802) obtains:

$$\zeta^B_{0\bar{0}} = 0.029 \pm 0.057$$

- Comparison with quantum optics tests: precision O(10^{-3})

QG induced CPTV in correlated Kaon system

In presence of decoherence and CPT violation induced by quantum gravity (CPT operator "ill-defined") the definition of the particle-antiparticle states could be modified. This in turn could induce a breakdown of the correlations imposed by Bose statistics (EPR correlations) to the kaon state [Bernabeu, et al. PRL 92 (2004) 131601, NPB744 (2006) 180]:

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

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

Fit of $I(\pi^+\pi^-,\pi^+\pi^-;\Delta t,\omega)$:

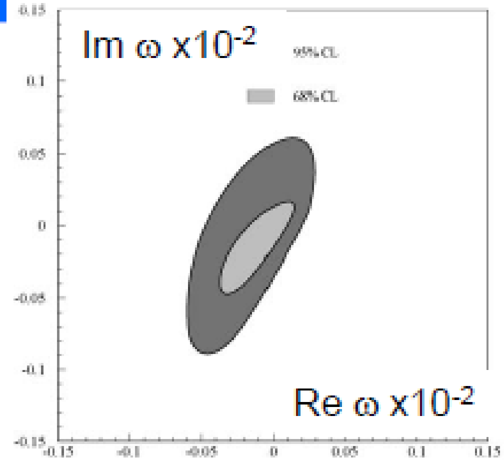
L=1.5 fb^{-1}

KLOE FINAL :

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

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

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



- Improvement x 2 wrt published KLOE

- In the B system [Alvarez, Bernabeu, Nebot JHEP 0611, 087]

$$-0.0084 \le \Re\omega \le 0.0100 \quad \text{at } 95\%\ \text{C.L.}$$

Scalars

Light scalars in ϕ radiative decays

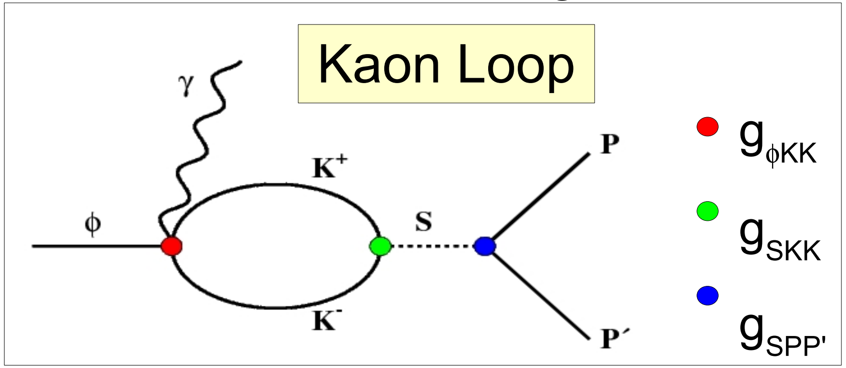
Scalar structure below 1 GeV is an open point: $\bar{q}q$, $\bar{q}\bar{q}qq$, **KK** molecule...

BR and mass spectra of $\phi \to PP'\gamma$ sensitive to intermediate scalar meson structure

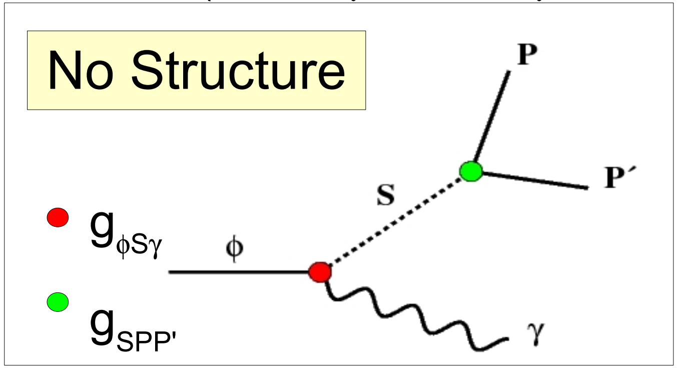
At KLOE PP':

$\pi^0\pi^0$	$\Rightarrow$	$f_0(980)/\sigma(600)$	EPJC49(2007)473, PLB537(2002)21
$\pi^+\pi^-$	$\Rightarrow$	$f_0(980)/\sigma(600)$	PLB634(2006)148
$\eta\pi^0$	$\Rightarrow$	$a_0(980)$	arXiv:0904.2539, PLB536(2002)209
K_SK_S	$\Rightarrow$	$f_0(980)/a_0(980)$	PLB679(2009)10

Phenomenological models used to describe $\phi \to S\gamma \to PP'\gamma$:

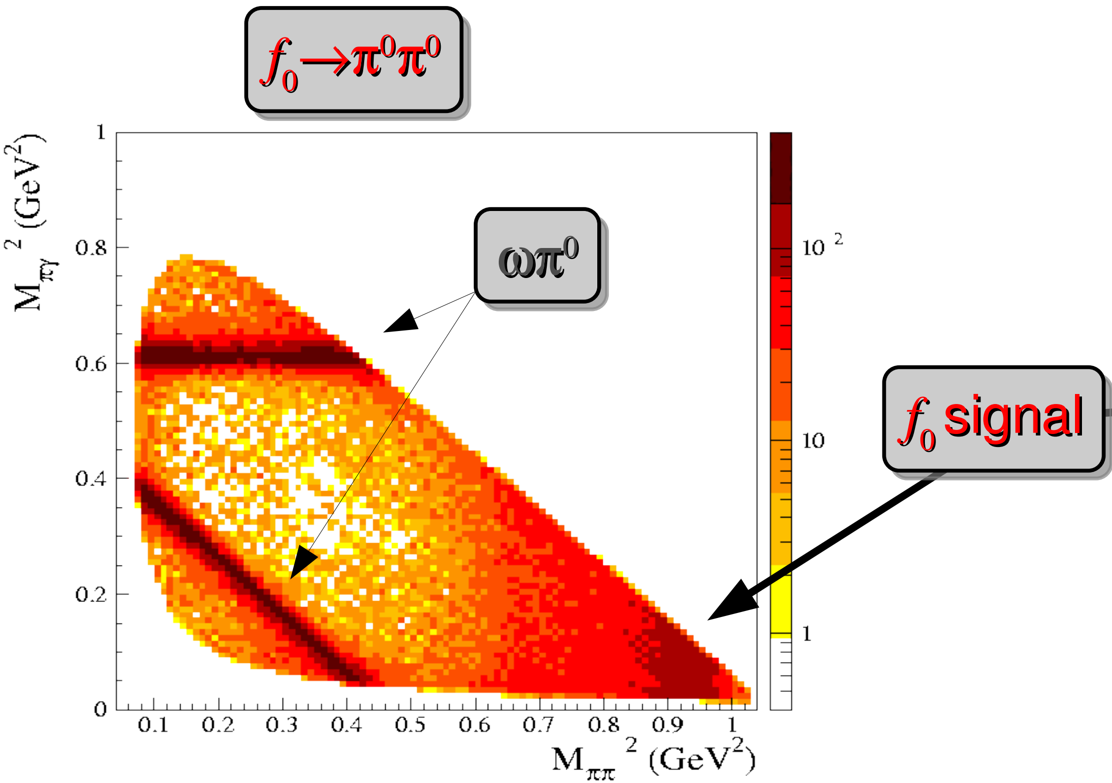


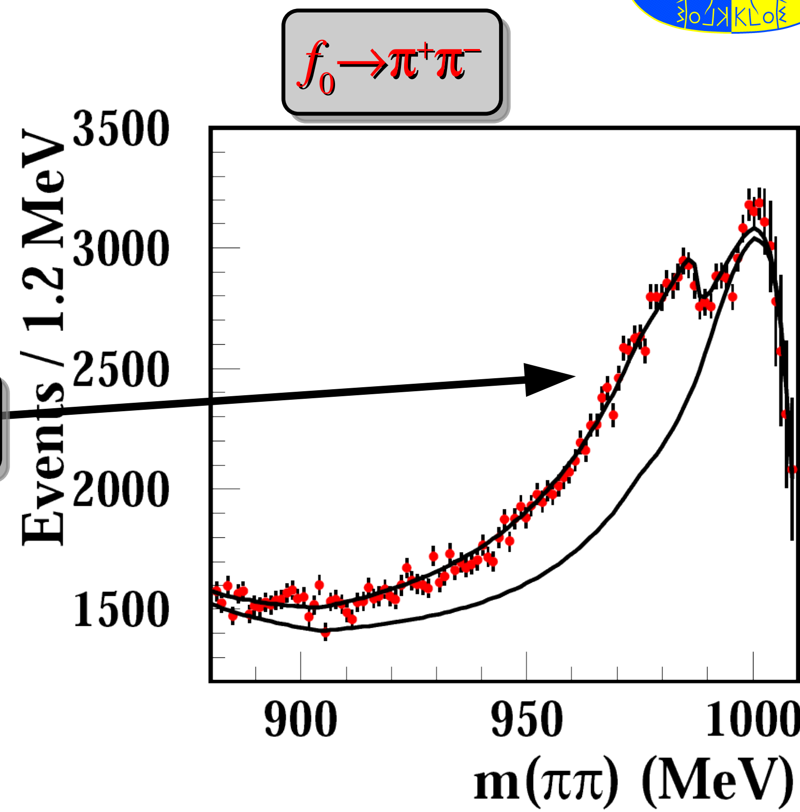
N. Achasov *et al.* NPB315(1989) 465
N. Achasov *et al.* PRD56(1997) 4084
N. Achasov *et al.* PRD68(2003) 014006



G. Isidori *et al.* JHEP 05(2006) 049

f_0 spectrum fit





KAON LOOP
Fit result

Channel	M_{f0} (MeV)	g_{f0KK} (GeV)	$g_{f0\pi\pi}$ (GeV)	$g^2_{f0KK} / g^2_{f0\pi\pi}$
$\pi^0\pi^0\gamma$	984.7± 1.9 $_{mod}$	3.97 ± 0.43$_{mod}$	−1.82± 0.19 $_{mod}$	~4.8
$\pi^+\pi^-\gamma$	983.7	4.74	−2.22	~4.6

Fit to $\eta\pi^0$ mass distribution

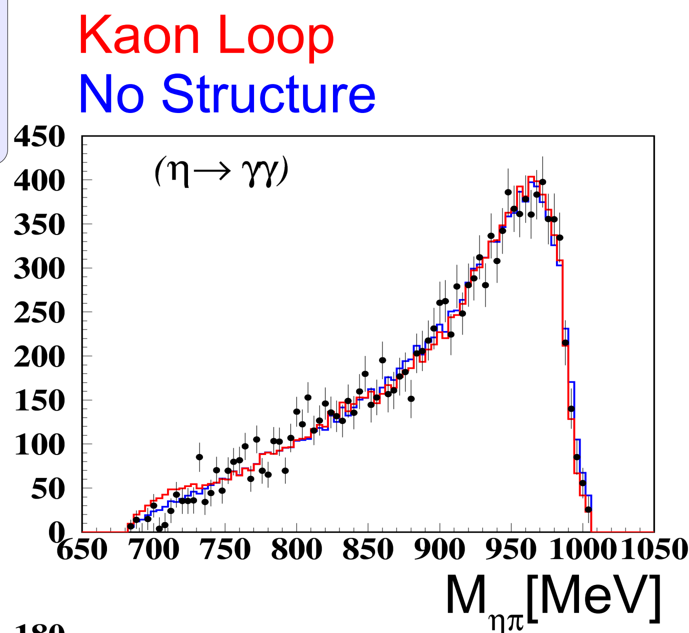
$\eta \to \gamma\gamma$ $BR(\phi \to \eta\pi^0\gamma) = (7.01 \pm 0.10_{sta} \pm 0.20_{sys}) \times 10^{-5}$

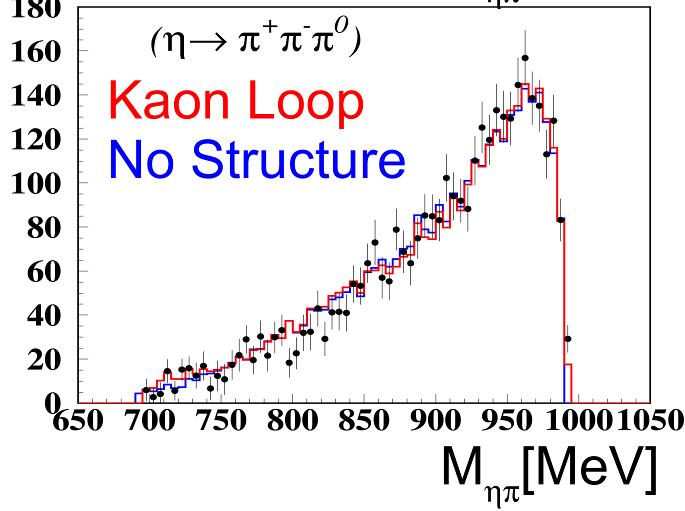
$\eta \to \pi^+\pi^-\pi^0$ $BR(\phi \to \eta\pi^0\gamma) = (7.12 \pm 0.13_{sta} \pm 0.22_{sys}) \times 10^{-5}$

Distribution unfolded to account for detector resolution

Fit with both KL and NS models

M_{a0} [MeV]	982.5 ± 1.6 ± 1.1	982.5 (fixed)
g_{a0K+K-}[GeV]	2.15 ± 0.06 ± 0.06	2.01 ± 0.07 ± 0.28
$g_{a0\eta\pi0}$[GeV]	2.82 ± 0.03 ± 0.04	2.46 ± 0.08 ± 0.11
$g_{\phi a0\gamma}$[GeV]	1.58 ± 0.10 ± 0.16	1.83 ± 0.03 ± 0.08
$BR(\phi \to \rho\pi \to \eta\pi\gamma)$	0.92 ± 0.40 ± 0.15	0.05 ± 4 ± 0.07
$BR(\phi \to \rho\pi \to \eta\pi\gamma)$	1.70 ± 0.04 ± 0.03	1.70 ± 0.03 ± 0.01
$P(\chi^2)$	0.104	0.309





Search for $\phi \to K_S K_S \gamma$

KLOE PLB679(2009)10

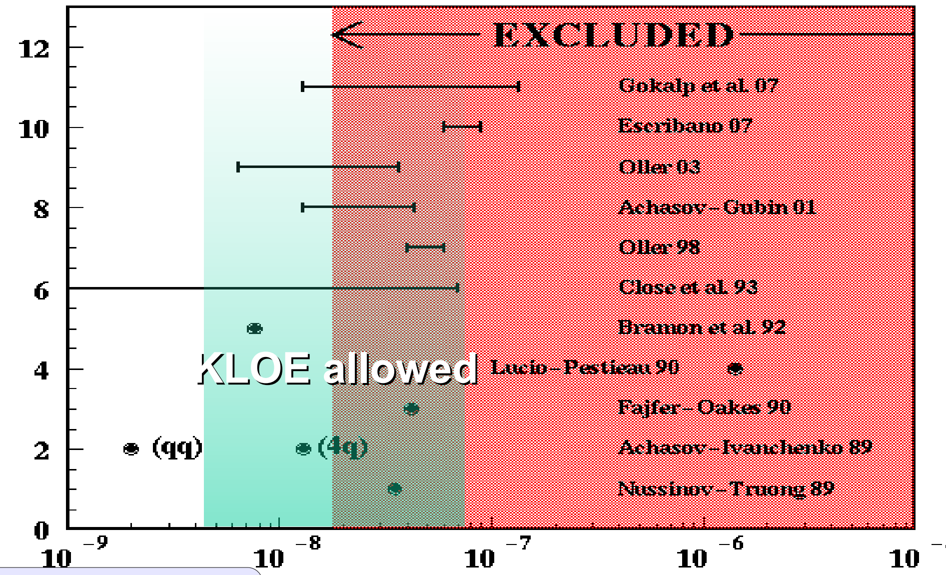
After all cuts we are left with 5 events in data and 3.2 in MC

$$BR(\phi \to (f_0 + a_0)\gamma \to K^0\bar{K}^0\gamma) < \frac{UL(\mu_{sig}) \text{ at } 90\% \text{ C.L.}}{\int Ldt \cdot \sigma(e^+e^- \to \phi)\cdot\frac{1}{2}\cdot BR(K_S \to \pi^+\pi^-)^2 \cdot \varepsilon}$$

Selection efficiency on the signal is (24.8±0.5)%

UL(μ_{sig}) at 90% CL = 6.79 using Unified Approach by Feldman-Cousins

Phys. Rev. D57 (1998) 3873



$BR(\phi \to K^0\bar{K}^0\gamma)$

$BR(\phi \to \bar{K}_0 K_0 \gamma) < 1.9\times10^{-8}$ @ 90 % C.L.

Pseudoscalars

$\eta \rightarrow \pi^+\pi^-e^+e^-$

Poorly measured (4 events CMD-2, 15 events CELSIUS-WASA)

BR predicted by ChPT and VMD models

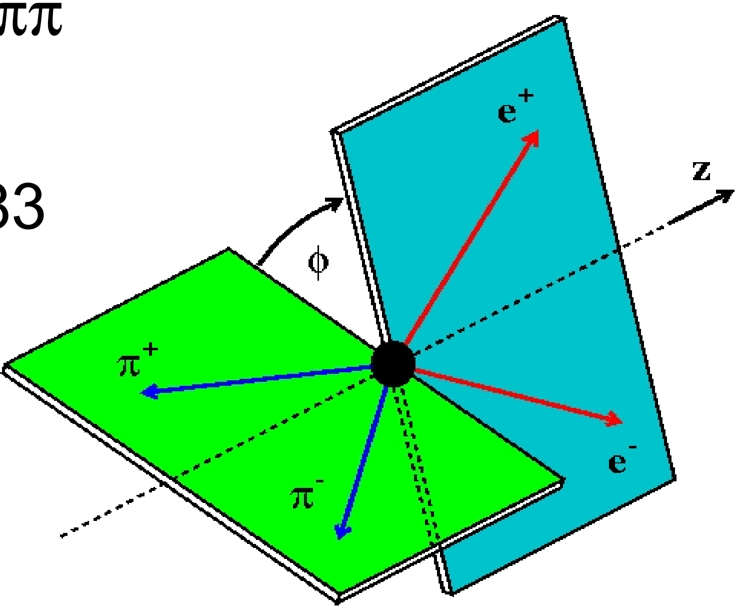
η structure using virtual photon

Angular asymmetry between ee and ππ

Test of non-CKM CP violation

Gao, Mod. Phys. Lett. A17(2002) 1583

KLOE PLB675(2009)283



Within SM constrained by BR(η→ππ):

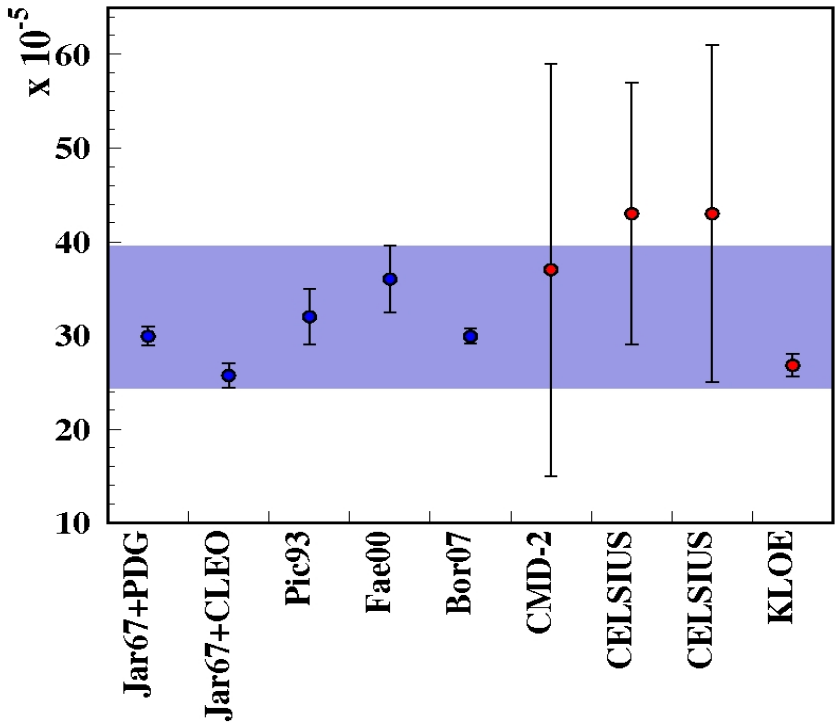
Experiment: $A_\phi < 10^{-4}$

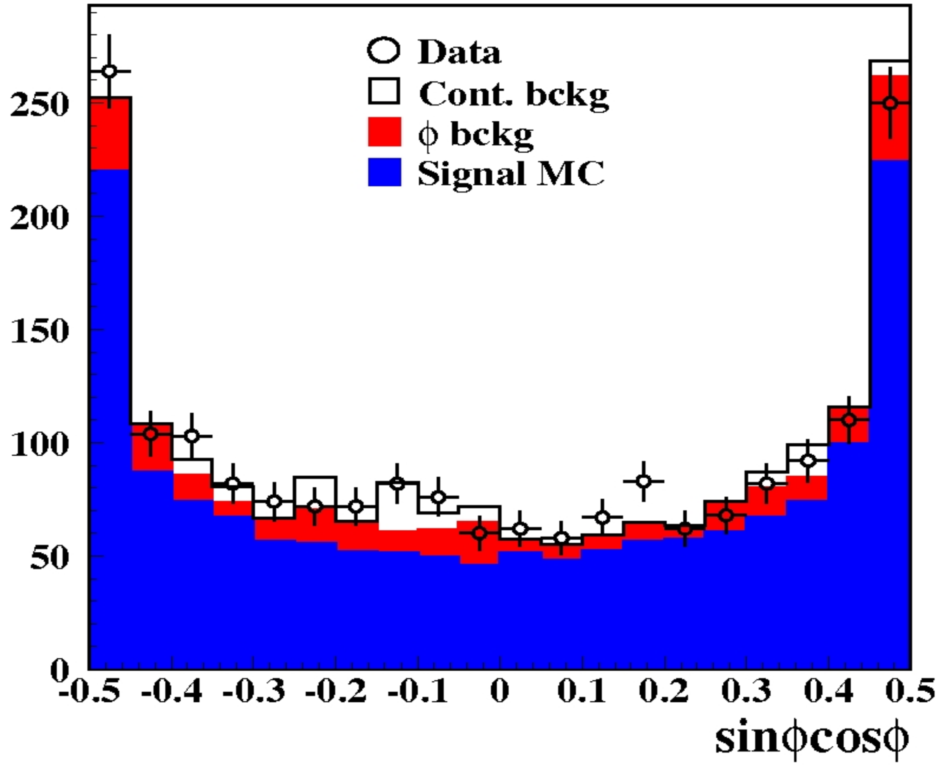
Theory: $A_\phi \sim 10^{-15}$

The unconventional CPV term can increase A_ϕ up to 10^{-2}

BR and Asymmetry

$$BR(\eta \rightarrow \pi^+\pi^- e^+e^-(\gamma)) = (26.8 \pm 0.9_{Stat.} \pm 0.7_{Syst.}) \cdot 10^{-5}$$





$$A_\phi = (-0.6 \pm 2.5_{Stat.} \pm 1.8_{Syst.}) \cdot 10^{-2}$$

First measurement!

$\eta \rightarrow e^+e^- e^+e^-$

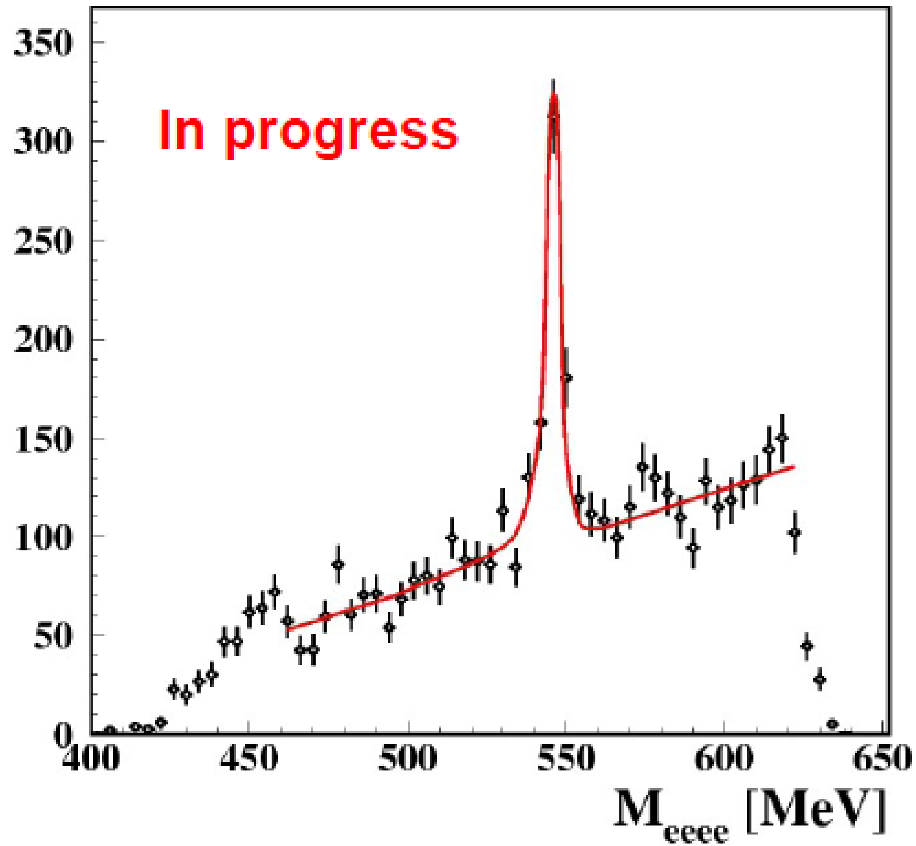
Data sample: 1.7 fb^{-1}

Photon conversion on Beam Pipe
and Drift Chamber wall rejected

Remaining background from
ϕ decay is subtracted

Fit M_{eeee} distribution for signal
and continuum bckg
to obtain shapes

These are used to fit M_{eeee}
distribution for data



N_{eeee} = 413 ± 31

First observation!

η/η' mixing

KLOE PLB 648 (2007)

- $\phi \to \eta'\gamma \quad \eta' \to \pi^+\pi^-\eta \quad \eta \to 3\pi^0$
- $\phi \to \eta'\gamma \quad \eta' \to \pi^0\pi^0\eta \quad \eta \to \pi^+\pi^-\pi^0$
- $\phi \to \eta\gamma \quad \eta \to 3\pi^0$

Allowing also for gluonium content in η' we fit the following ratios of BR:

$$R_\phi = \frac{BR(\phi\to\eta'\gamma)}{BR(\phi\to\eta\gamma)} = 4.77 \pm 0.09 \pm 0.19$$

$$|\eta'\rangle = X_{\eta'}\frac{1}{\sqrt{2}}|u\bar{u}+d\bar{d}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_{\eta'}|glue\rangle$$

$$|\eta\rangle = \cos\varphi_P \frac{1}{\sqrt{2}}|u\bar{u}+d\bar{d}\rangle + \sin\varphi_P|s\bar{s}\rangle$$

$$\frac{\Gamma(\eta'\to\rho\gamma)}{\Gamma(\omega\to\pi^0\gamma)} = C_{M2} Z_{NS}\left(\sin(\varphi_G)\cos(\varphi_P)\right)^2$$

$$R_\phi = \cot^2(\varphi_P)\cos^2(\varphi_G)\left(1 - C_V \frac{Z_{NS}}{Z_N}\frac{1}{\sin(2\varphi_P)}\right)^2\left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

$$\frac{\Gamma(\eta'\to\gamma\gamma)}{\Gamma(\pi^0\to\gamma\gamma)} = C_{M1}\left(5\cos(\varphi_G)\sin(\varphi_P) + \sqrt{2}\frac{f_q}{f_s}\cos(\varphi_G)\cos(\varphi_P)\right)^2$$

$$\frac{\Gamma(\eta'\to\omega\gamma)}{\Gamma(\omega\to\pi^0\gamma)} = C_{M3}\left(Z_{NS}\sin(\varphi_G)\cos(\varphi_P) + 2C_V Z_S \sin(\varphi_G)\sin(\varphi_P)\right)^2$$

$$X_{\eta'} = \cos\varphi_G \cos\varphi_P$$

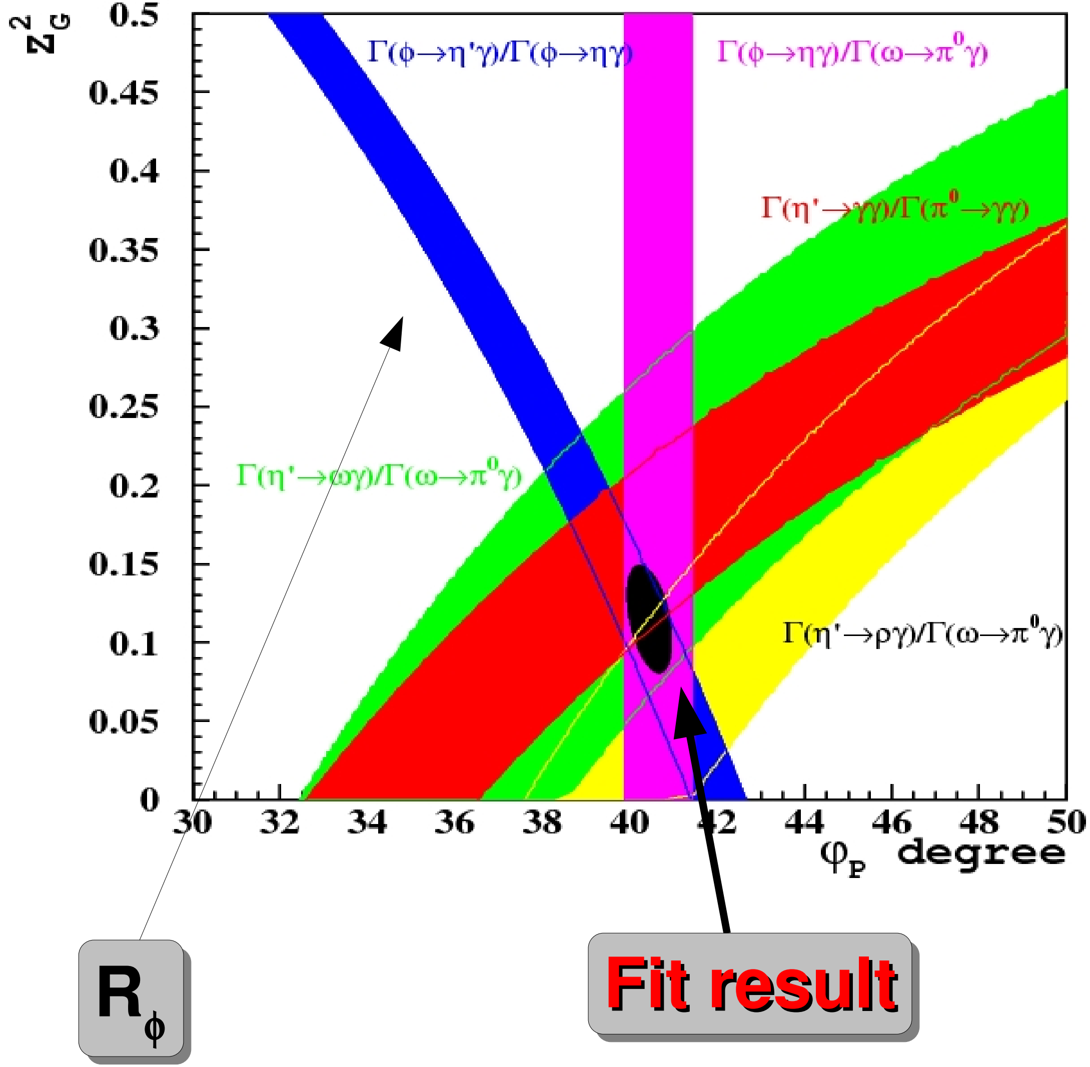
$$Y_{\eta'} = \cos\varphi_G \sin\varphi_P$$

$$Z_{\eta'} = \sin\varphi_G \quad \leftrightarrow$$ **Gluonium content**

Rossner PRD27(1983)1101
Bramon PLB503(2001)271
Escribano JHEP05(2007)6

Gluonium content in η'

KLOE JHEP07(2009)105



Fit done using:

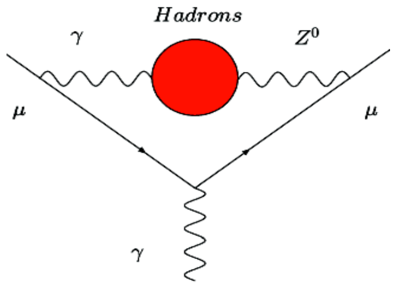
- updated value from PDG08
- KLOE ω BR
- More experimental inputs

3σ evidence of gluonium content in η'

	Gluonium allowed	Gluonium at zero
$\chi^2/n.d.f(Prob)$	4.6/3 (20.5 %)	14.7/4 (.5 %)
Z_G^2	0.115 ± 0.036	0 fixed
φ_P	$(40.4 \pm 0.6)°$	$(41.4 \pm 0.5)°$
Z_{NS}	0.936 ± 0.025	0.927 ± 0.023
Z_S	0.83 ± 0.05	0.82 ± 0.05
φ_V	$(3.32 \pm 0.09)°$	$(3.34 \pm 0.09)°$
$m_s/\bar{m}$	1.24 ± 0.07	1.24 ± 0.07

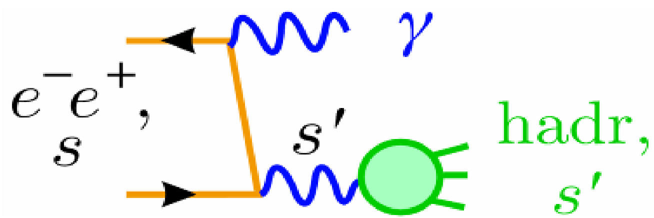
Cross sections

Hadronic cross section and a_μ



$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3} \int_{0.35\,\mathrm{GeV}^2}^{0.95\,\mathrm{GeV}^2} ds\, \sigma(e^+e^- \to \pi^+\pi^-)\, K(s) \longrightarrow \propto \frac{1}{s}$$

Radiative return



KLOE has shown, for the first time, that it is possible to measure $\sigma(e^+e^- \to \pi^+\pi^-\gamma)$ at fixed $\sqrt{s}$ with high accuracy using ISR to extract $\sigma(e^+e^- \to \pi^+\pi^-)$ for $\sqrt{s'}$ from $2M_\pi$ to $\sqrt{s}$

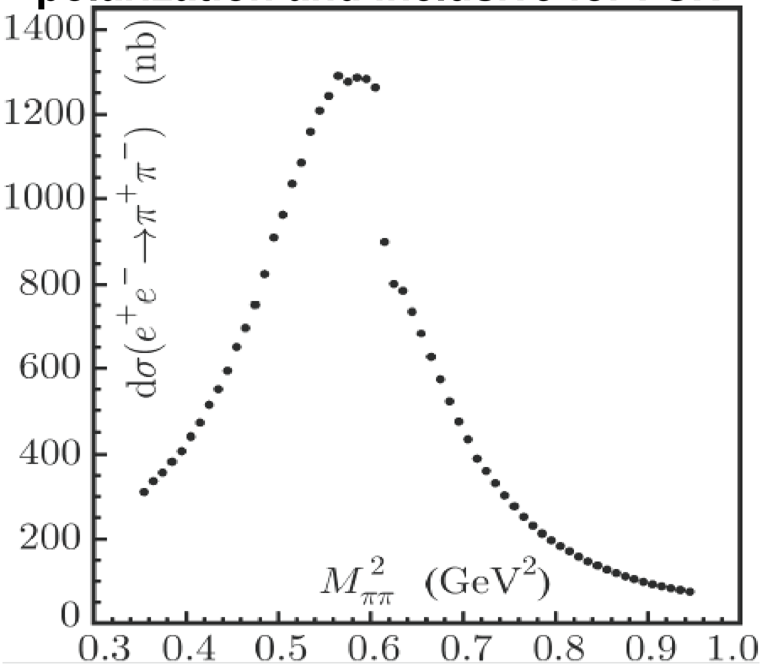
$$s\frac{d\sigma_{\pi\pi}}{dM^2_{\pi\pi}} = \sigma_{\pi\pi}(s) \times H(s)$$

Requires precise calculations of the radiator function H(s)
PHOKHARA MC NLO generator
[EPJC27(2003)]

$\sigma\ (e^+e^- \to \pi^+\pi^-)$

KLOE PLB670(2009)285

$\sigma_{\pi\pi}$ *vs* $M^0_{\pi\pi}$, undressed from vacuum polarization and inclusive for FSR



$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3} \int_{0.35\,\mathrm{GeV}^2}^{0.95\,\mathrm{GeV}^2} ds\, \sigma(e^+e^- \to \pi^+\pi^-)\, K(s)$$

Systematic errors on $a_\mu^{\pi\pi}$:

Experimental fractional error = 0.6 %

Reconstruction Filter	negligible
Background	0.3%
Trackmass/Miss. Mass	0.2%
π/e-ID and TCA	negligible
Tracking	0.3%
Trigger	0.1%
Acceptance ($\theta_{\pi\pi}$)	0.1%
Acceptance (θ_π)	negligible
Unfolding	negligible
Software Trigger	0.1%
√s dep. Of H	0.2%
Luminosity ($0.1_{th} \oplus 0.3_{exp}$)%	0.3%

Theoretical fractional error = 0.6 %

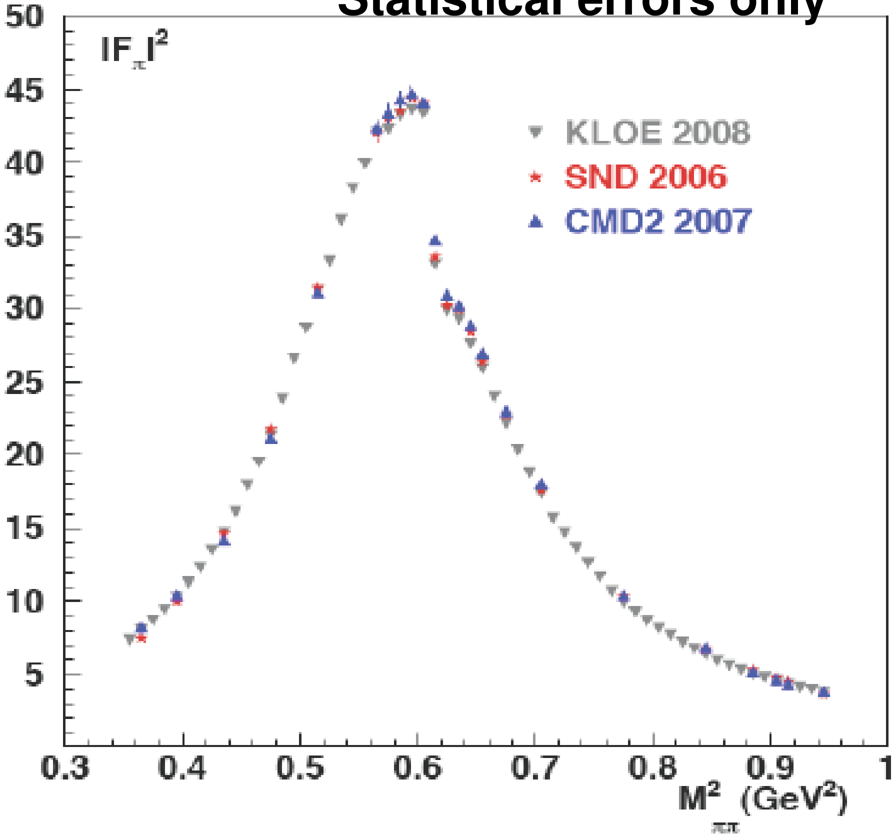
FSR resummation	0.3%
Radiator H	0.5%
Vacuum polarization	0.1%

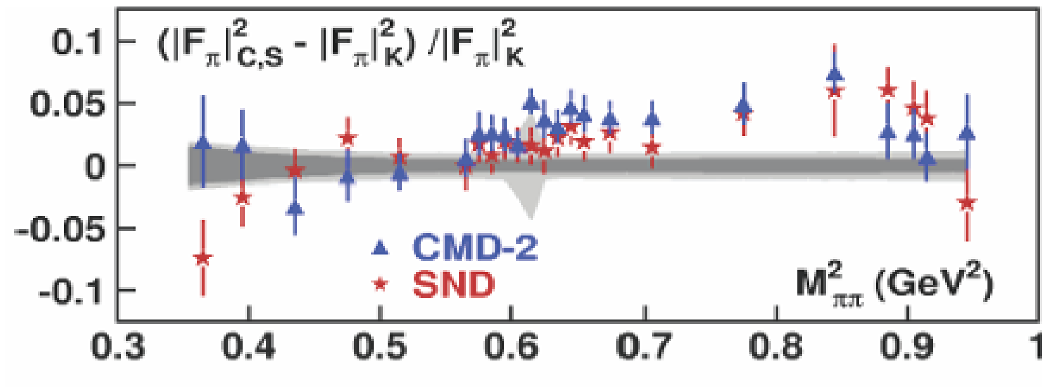
$a_\mu^{\pi\pi}(0.35\text{–}0.95\ \mathrm{GeV}^2) = (387.2 \pm 0.5_{stat} \pm 2.4_{syst} \pm 2.3_{the}) \times 10^{-10}$

Comparison with other measurements

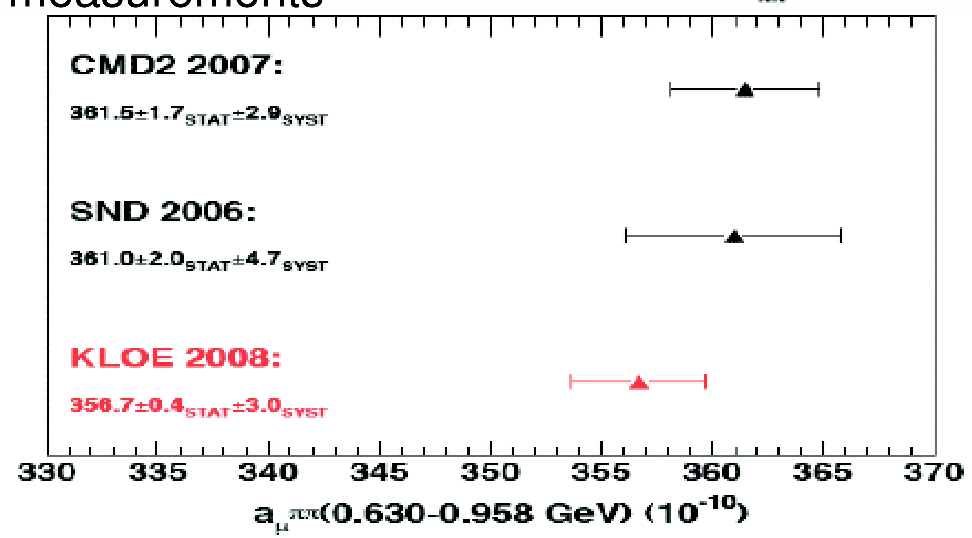
$$|F_\pi|^2 = \frac{3s}{p\,\alpha^2 \beta_\pi^3}\,\sigma_{\pi\pi}(s)$$

Statistical errors only





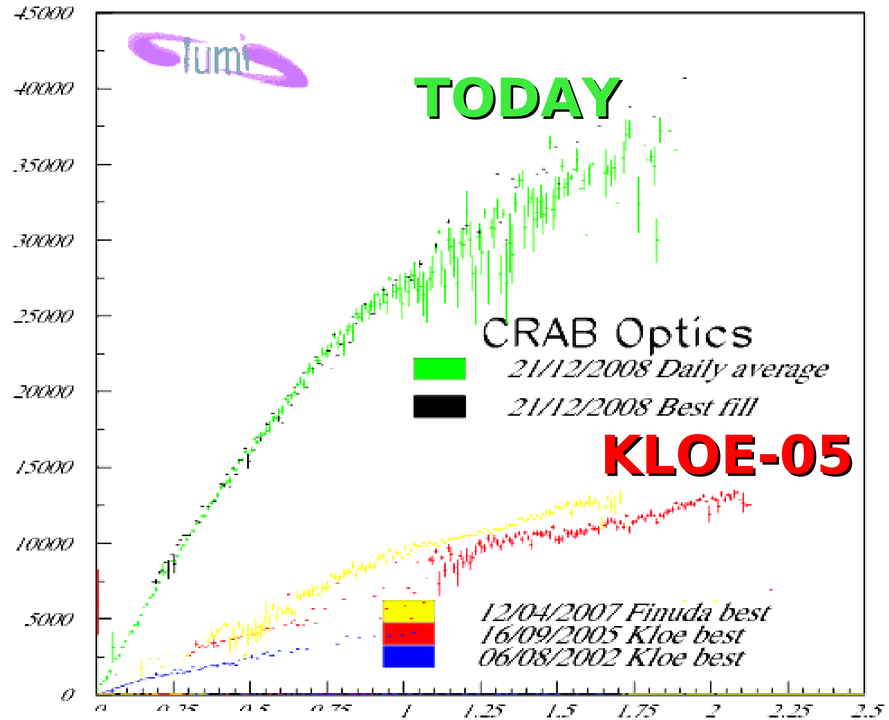
Integrated in the same range of other measurements



Future perspective KLOE-2

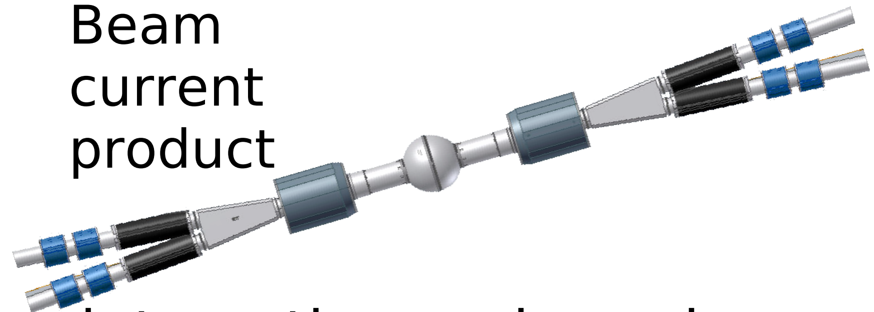
New DAFNE interaction scheme

New machine magnetic scheme:
CRAB WAIST
Big improvement with same beam currents



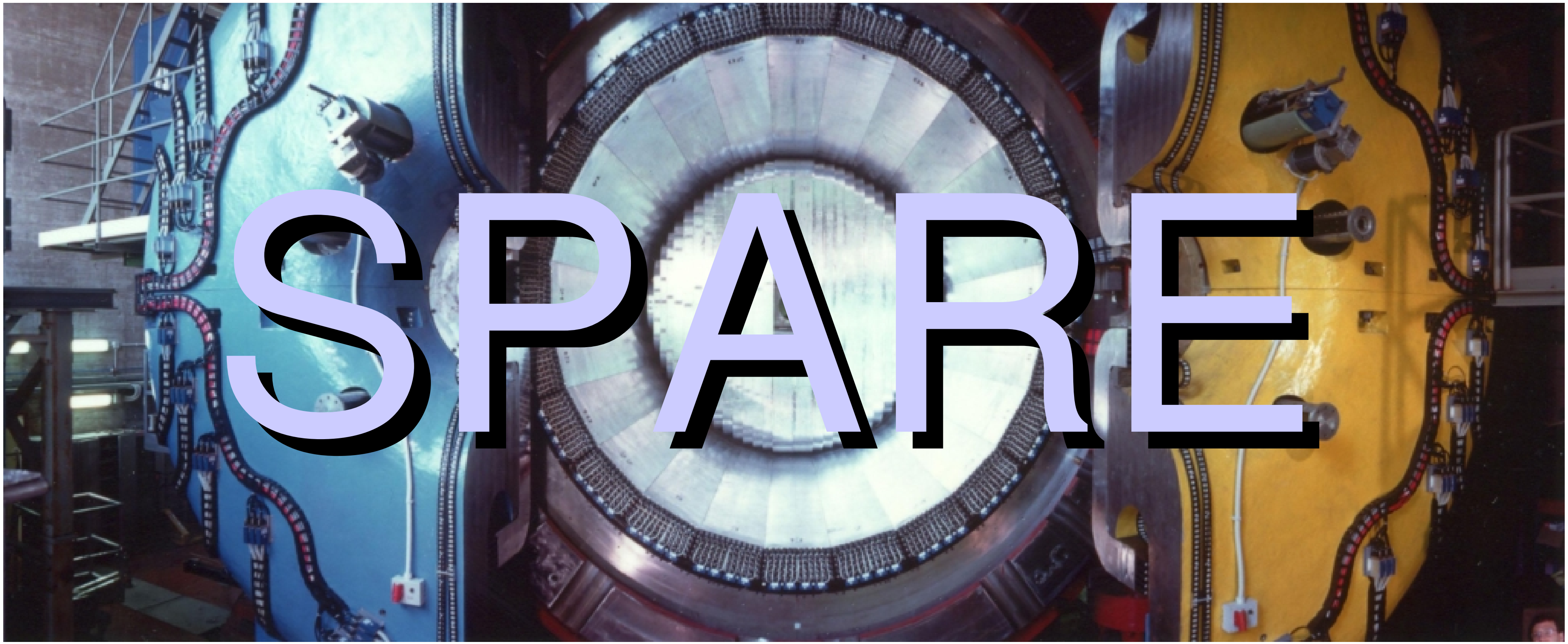
Beam current product

Future **DATA TAKING** plans:
STEP-0[2009]: 5fb^{-1}
γγ taggers
STEP-1[2011]: >20fb^{-1} with:
Inner Tracker
Low Angle Cal
Quadrupole Cal



New interaction region scheme
Larger crossing angle

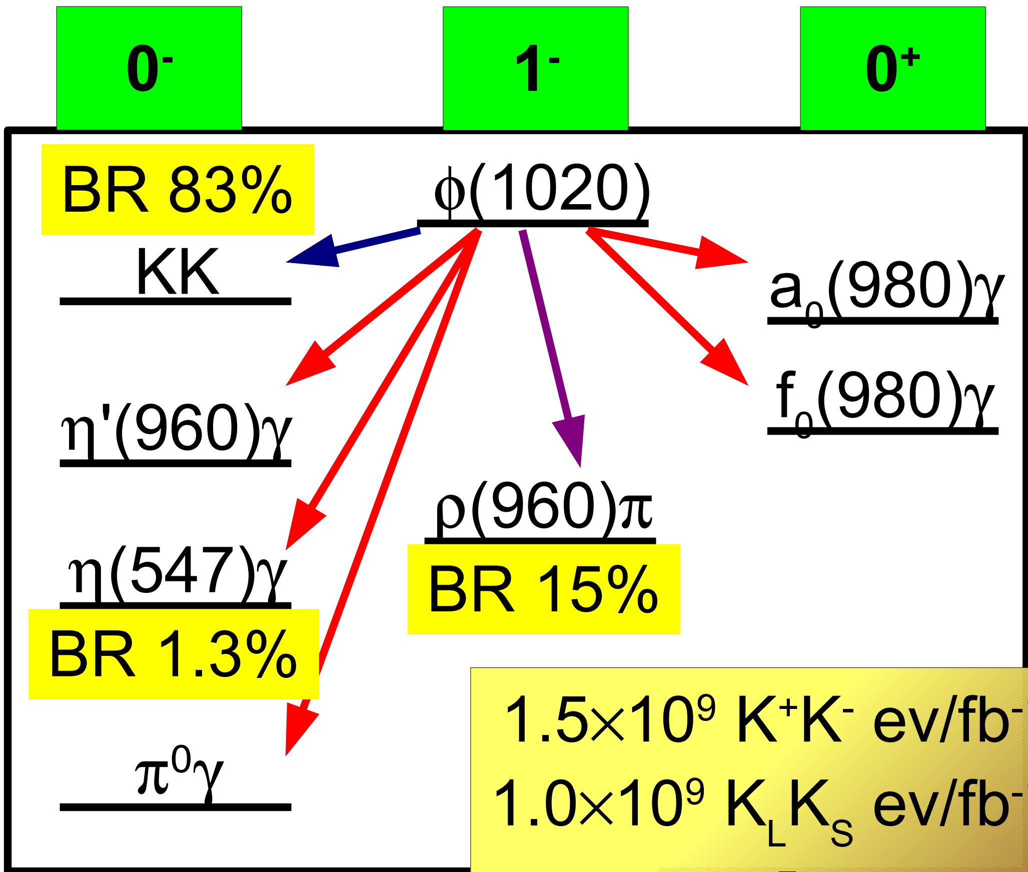
For more information:
http://www.lnf.infn.it/kloe2


SPARE

Physics at a Φ-factory

KLOE experiment acquire data at DAΦNE φ-factory

A φ-factory is a collider e^+e^- running at $\sqrt{s} = M_\phi$



1.5×10^9 K^+K^- ev/fb^{-1}

1.0×10^9 K_LK_S ev/fb^{-1}

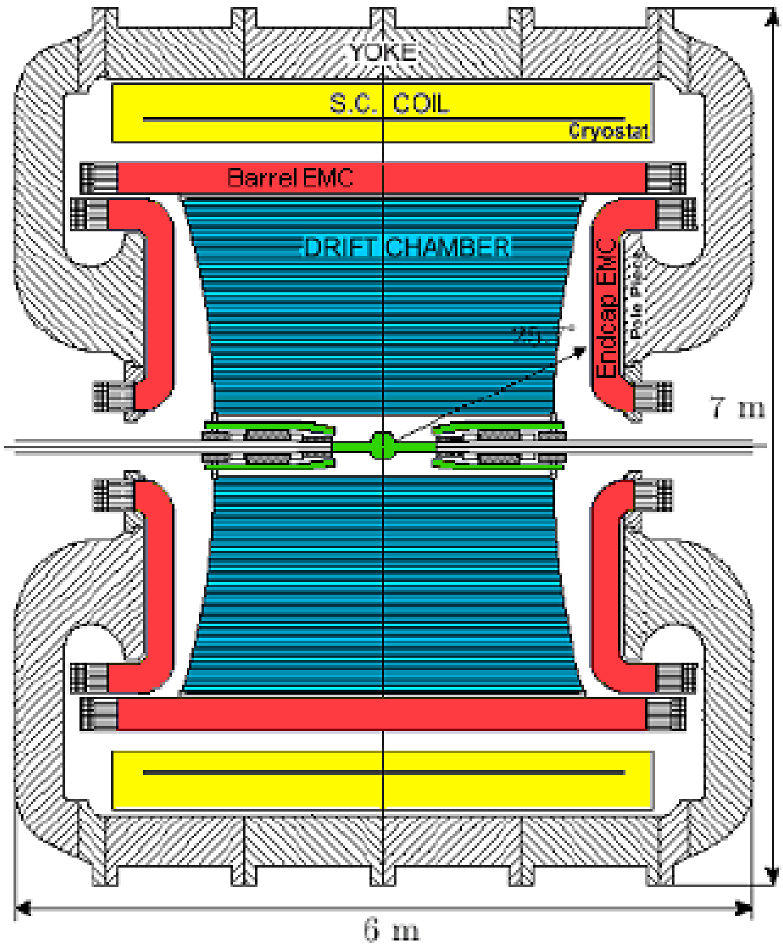
5×10^7 η ev/fb^{-1}

KAON physics
- CP violation
- CPT and QM tests:
  - interferometry and charge asymmetries
- CKM Matrix V_{us}
- Rare Kaon decays

Non Kaon Physics
- Hadronic cross section
- Radiative φ decays (hadron spectroscopy)

Detector description

The KLOE experiment



Be beam pipe (0.5 mm thick)
Instrumented permanent magnet quadrupoles (32 PMTs)

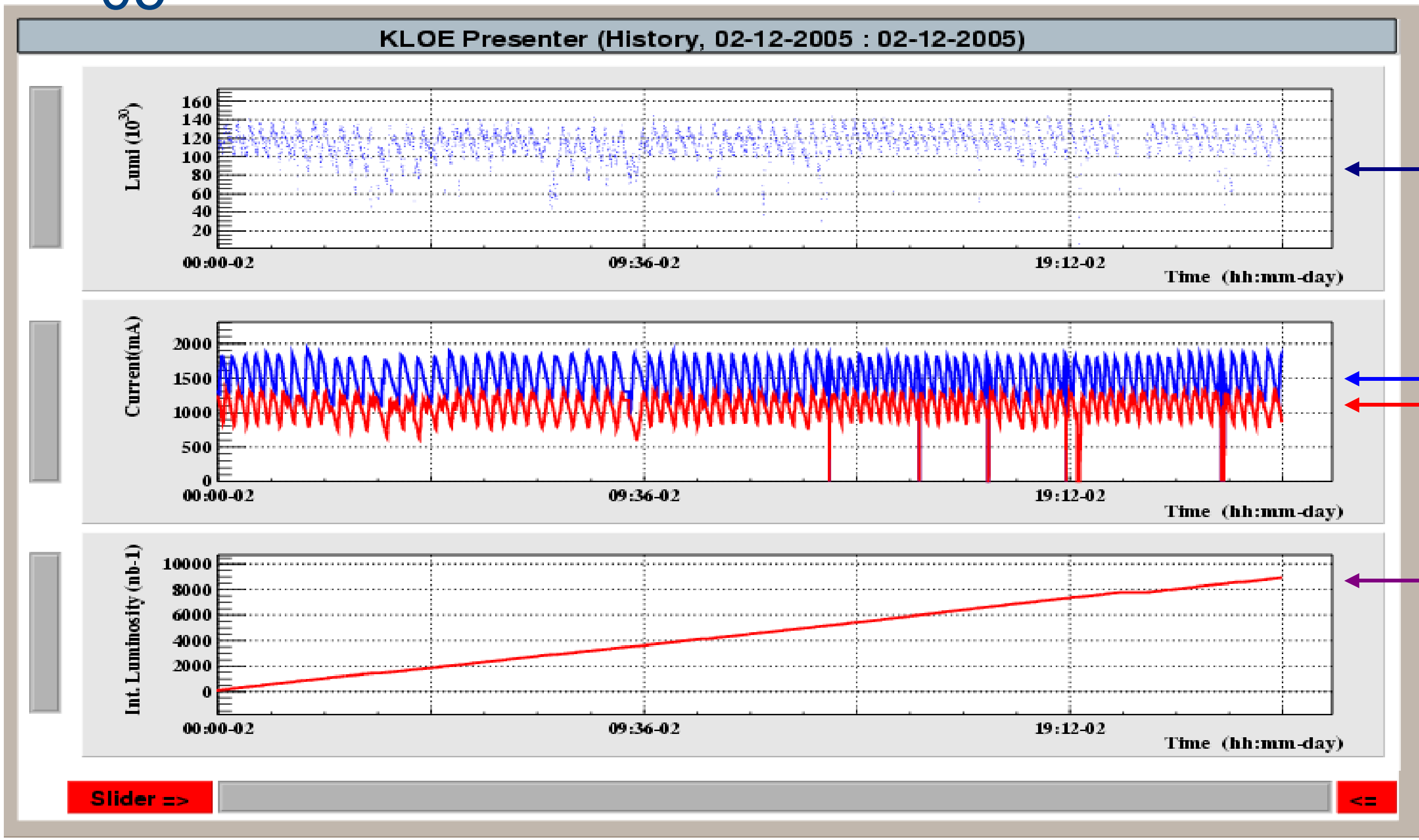
Drift chamber (4 m ∅ × 3.3 m)
90%He+10% IsoB, composite frame
12582 stereo sense wires

Electromagnetic calorimeter
Lead/scintillating fibers
4880 PMTs

Superconducting coil (5 m bore)
$B = 0.52$ T ($\int B\, dl = 2$ T·m)

DAΦNE Best performance

DAΦNE 24h performance in topping-up mode, december 05



$L = 1.2 \cdot 10^{32}$ $cm^{-2}\ s^{-1}$

$I(e^-) = 1.6$ A

$I(e^+) = 1.1$ A

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

K LOng Experiment

Detector design driven by the measurement of direct CPV through the double ratio:

$$R = \Gamma(K_L \to \pi^+\pi^-)\ \Gamma(K_S \to \pi^0\pi^0)\ /\ \Gamma(K_S \to \pi^+\pi^-)\ \Gamma(K_L \to \pi^0\pi^0)$$

Collect as much possible K_L

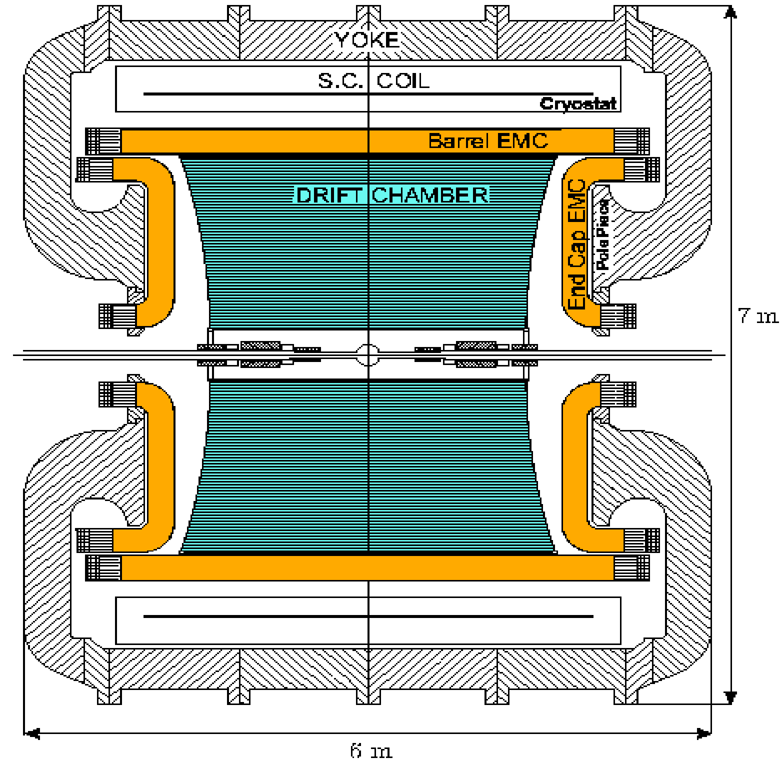
$\lambda(K_L) \sim 350$ cm $\Rightarrow$ big volume

Good reconstruction of the kaon decay vertex

Magnetic field value compromise:

highest for PID

smallest for tracking



KLOE – EMC calorimeter

Physics requirements:

High discriminant power on $K^0 \to 2\pi$ and $K^0 \to 3\pi^0$

Few mm accuracy on the K neutral decays vertex

⇓

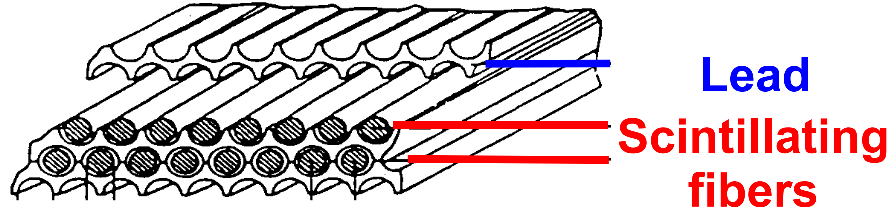
Hermetic ~4π

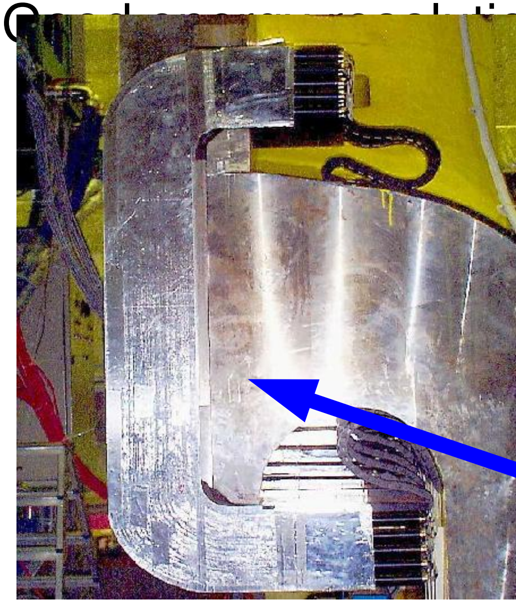
Excellent time resolution

~1 cm accuracy on the γ conversion point

Fully efficient in the range 20-300 MeV

Good energy resolution





Technical solution:

Fine sampling lead - scintillating fibers (1mm ∅)

1 mm fibers + 0.5 mm thick lead foils

fiber : lead : glue = 48 : 42 : 10

23 cm thick → 15 X_0

4880 PMT's

98% solid angle coverage

End-caps modules C-shaped (minimize dead zones)

Z coordinate through Δt between the two sides

EMC Calorimeter performance

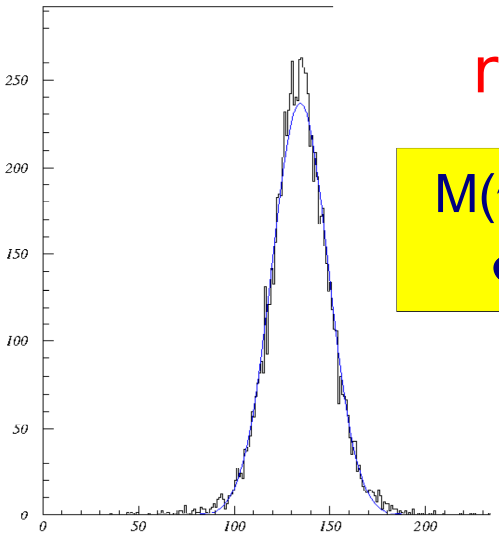
σ_t = 57 ps / √(E[GeV]) ⊕ 100 ps

σ_E = 0.057 / √(E[GeV])

σ_{shower} = 1.3 cm / √(E[GeV])

$\sigma_{vertex}(\gamma\gamma)$ = 1.5 cm ($K_L \to \pi^+\pi^-\pi^0$)

γγ mass resolution



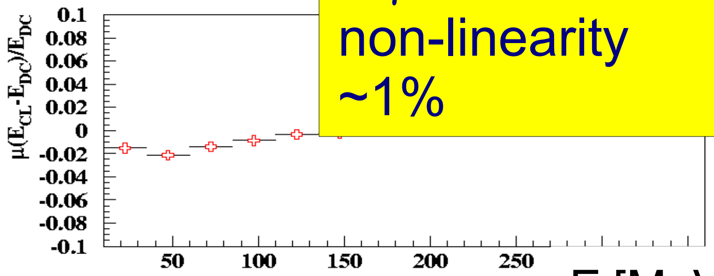
$M_{\gamma\gamma}$[MeV]

$M(\pi^0)$ = 134.5 MeV

σ_M ≈ 14.7 MeV

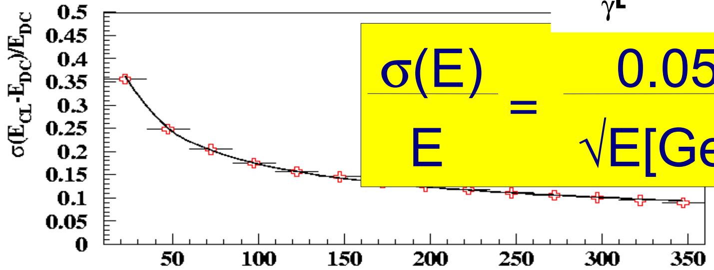
Energy resolution

$\phi \to \pi^+\pi^-\pi^0$ E_γ from tracking



non-linearity ~1%

E_γ[MeV]



$$\frac{\sigma(E)}{E} = \frac{0.057}{\sqrt{E[GeV]}}$$

E_γ[MeV]

ε > 95% with E_γ > 20 Mev

KLOE – Drift Chamber

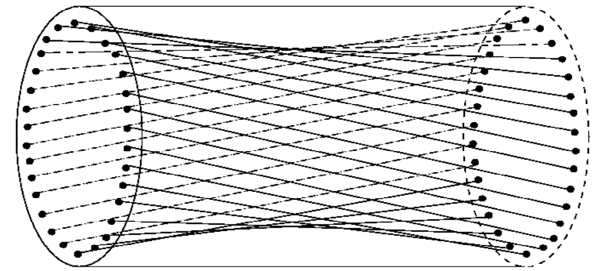
Physics requirements:

Large tracking volume (K_L decay length = 350 cm)

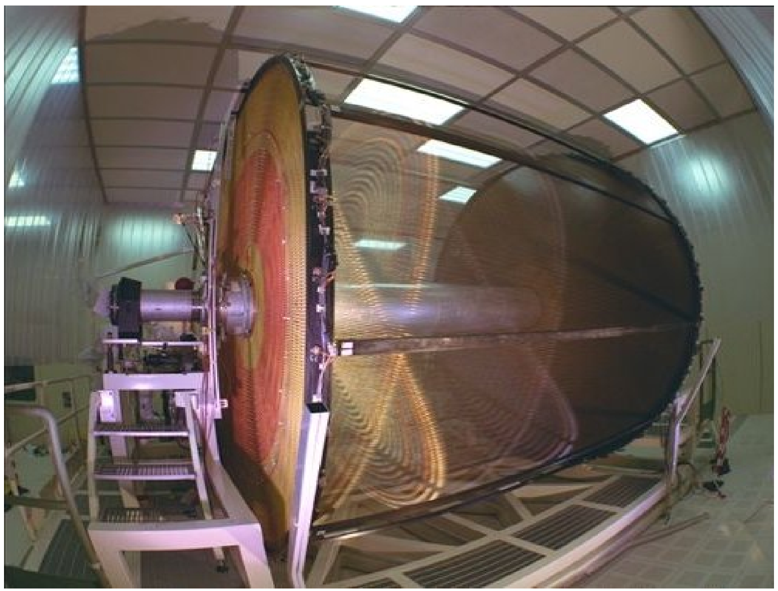
High and uniform reconstruction efficiency

Good momentum resolution

High Transparency



Technical solution:



80mm silver plated aluminium field wires

25 mm tungsten sense wires

Cell size = 2×2 cm^2 + 3×3 cm^2

layers (all stereo) = 58 (12 +46)

of channels = 12582 ; # of wires = 52140

Stereo angle (variable) = 60 ÷ 150 mrad

Gas mixture : 90% He + 10% C_4H_{10}

X_0 (gas + wires) ~900 m

C-fiber structure (0.7 mm – 8 mm) < 0.1 X_0

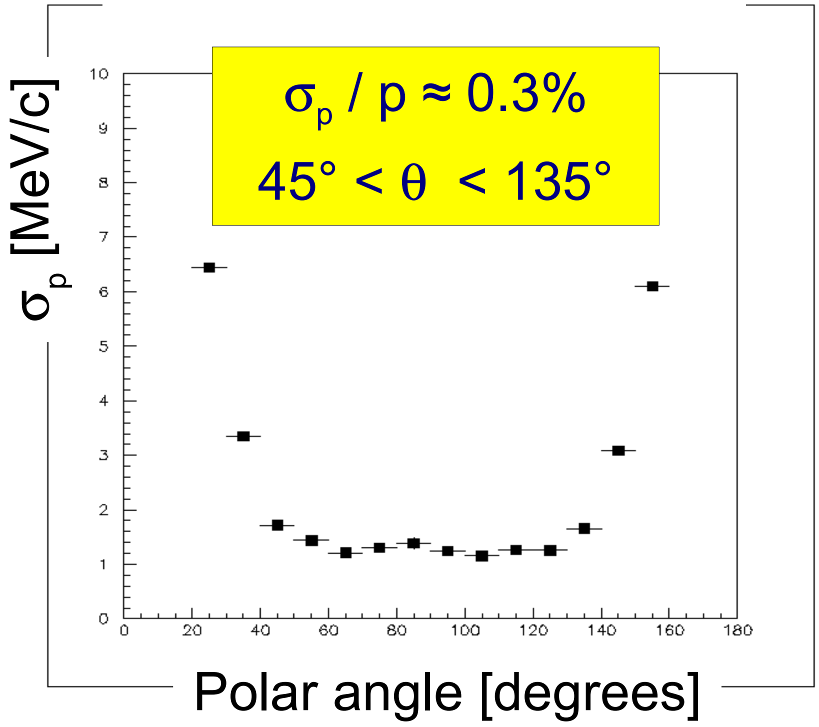
DC Performances

drift chamber resolution $\sigma_{r\phi} \approx 150\ \mu m$

Bhabha scattering events

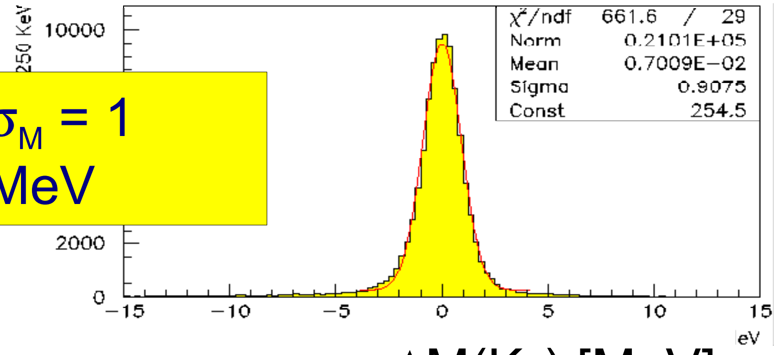
$\sigma_p / p \approx 0.3\%$

$45° < \theta < 135°$



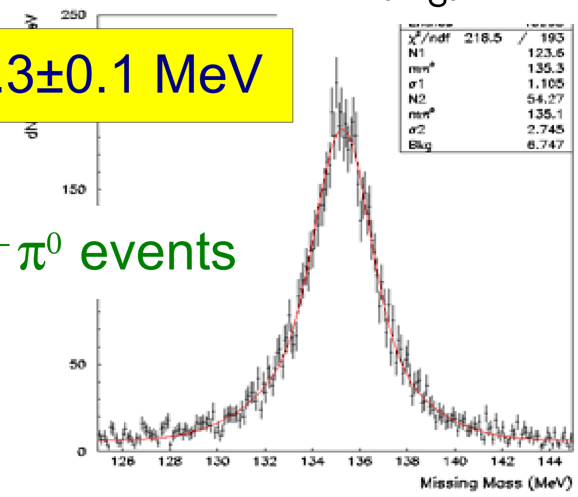
$K_S \rightarrow \pi^+\pi^-$ events

σ_M = 1 MeV



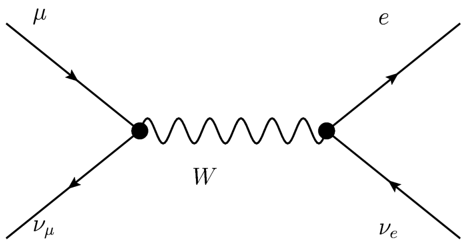
$M(\pi^0) = 135.3 \pm 0.1$ MeV

$K_L \rightarrow \pi^+\pi^-\pi^0$ events



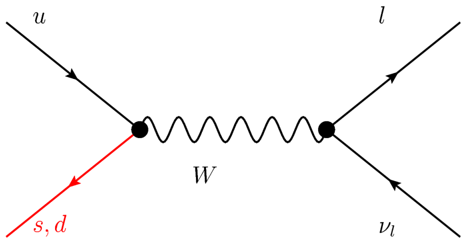
V_{us}

CKM unitarity: G_F universality

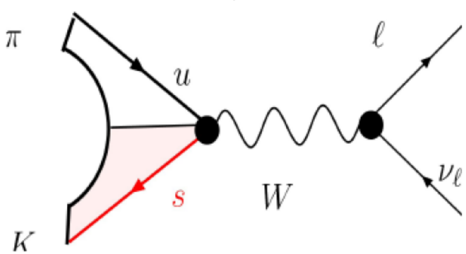


Universality of Weak coupling- $G_F = (g_W/M_W)^2$

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

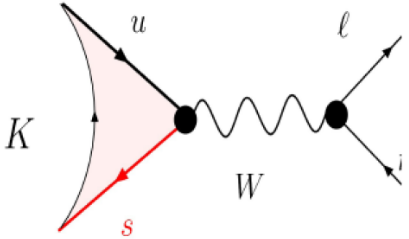


$$G_F = \frac{g_W^2}{4\sqrt{2}M_W^2}$$



$K_{\ell 3}$: K→ π ℓ ν

Precise determination of Vus
Test of Lepton universality (Ke3 vs Km3)
CKM unitary
Lepton-Quark universality of weak interaction



$K_{\ell 2}$: K→ ℓ ν

Precise determination of Vus/Vud (Km2/pm2)
Sensitivity to New Physics

Lepton Flavor violation test with Ke2/Km2

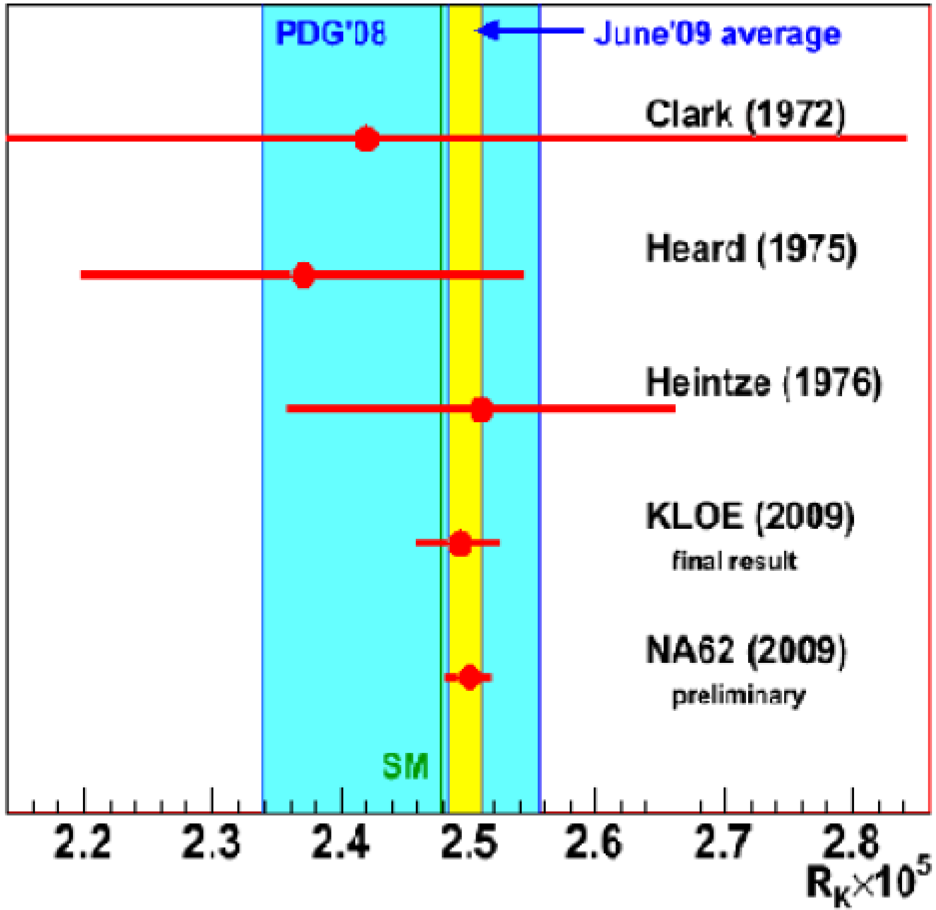
$K_{e2}/K_{\mu 2}$

R_K: World average

World average: R_K= 2.498(14)×10^{-5} (0.56%)

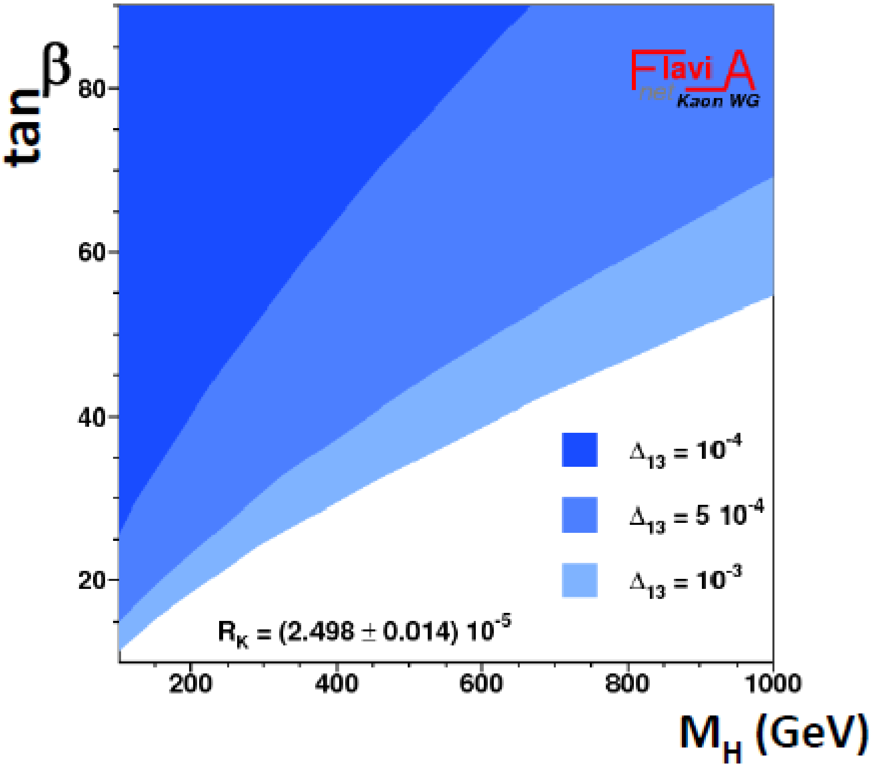
Includes NA62 preliminary (40% data set):

R_K= 2.500(16)×10^{-5} (0.64%)



R_K^{SM} = (2.477 ± 0.001) 10^{-5}

Sensitivity shown as 95%-CL excluded regions in the tanβ - M_H plane, for fixed values of the 1-3 slepton-mass matrix element, Δ_{13} = 10^{-3},0.5×10^{-3},10^{-4}



Kaon interferometry

Decoherence and CPTV from QG

Modified Liouville – von Neumann equation for the density matrix of the kaon system:

$$\dot{\rho}(t) = \underbrace{-iH\rho + i\rho H^{+}}_{\text{OM}} + L(\rho)$$

extra term inducing decoherence:
pure state => mixed state

$$L(\rho) = L(\rho; \alpha, \beta, \gamma)$$

$$\alpha, \gamma > 0 \quad , \quad \alpha\gamma > \beta^2$$

At most: $\alpha, \beta, \gamma = O\left(\frac{M_K^{\;2}}{M_{PLANCK}}\right) \approx 2 \times 10^{-20}$ GeV

Study of time evolution of **single kaons** decaying in π+π- and semileptonic final state

CPLEAR PLB 364, 239 (1999)

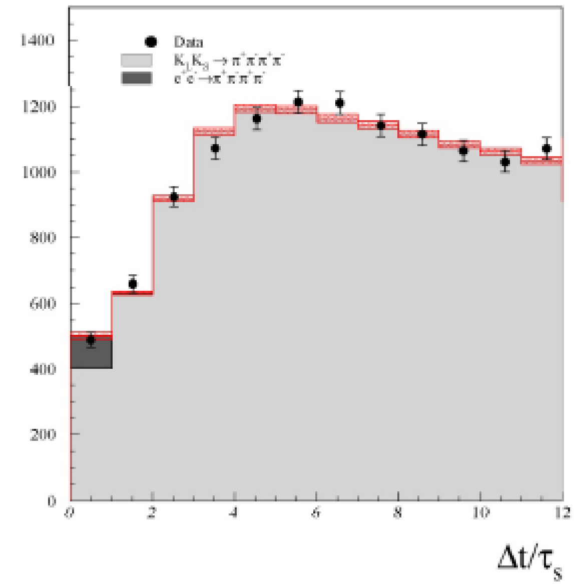
$$\alpha = (-0.5 \pm 2.8) \times 10^{-17}\ \text{GeV}$$
$$\beta = (2.5 \pm 2.3) \times 10^{-19}\ \text{GeV}$$
$$\gamma = (1.1 \pm 2.5) \times 10^{-21}\ \text{GeV}$$

In the complete positivity hypothesis
α = γ , β = 0
=> only one independent parameter: γ

The fit with $I(\pi^+\pi^-, \pi^+\pi^-; \Delta t, \gamma)$ gives:

KLOE FINAL L=1.5 fb^{-1}

$$\gamma = (0.7 \pm 1.2_{STAT} \pm 0.3_{SYST}) \times 10^{-21}\ \text{GeV}$$



Scalars

$\phi \rightarrow f_0\gamma$ signal selection

$\pi^0\pi^0 \leftarrow f_0 \rightarrow \pi^+\pi^-$

Event topology:
five neutral clusters above the quadrupole region ($\theta > 22°$) with **minimum energy** (7 MeV) and **proper time**.

Global **kinematic fit** (1^{st} only general constraint - 2^{nd} imposing the π^0 masses) used to **improve reconstruction** and to reject background (high χ^2 or $m_{\pi 0}$ out of range)

Signal event counting is performed on the **Mγγ vs Mππ** dalitz distribution

KLOE EPJC49(2007)473

Event topology:
two tracks and **one cluster** with minimum energy (10 MeV) and proper time. To reduce ISR contamination photon momenta at high polar angle ($\theta_\gamma > 45°$)

Rejection of the background using the **track mass** (particle mass value obtained form $\sqrt{s}$ value and tracks momenta)

Signal counting is performed by fitting the **invariant mass** spectrum of the **di-pion system**

KLOE PLB634(2006)148

$\phi \to a_0\gamma \to \eta\pi^0$ signal selection

Two different η decays modes used:

- $\eta \to \gamma\gamma$
- $\eta \to \pi^+\pi^-\pi^0$

KLOE Submitted to PLB

Event topology:
Five neutral clusters above quadrupole region with proper **energy** (>3MeV) and **time** ($<5\sigma_t$)

Global **kinematic fit** applied and relative χ^2 used to reject background (first only general assumption – second assuming masses)

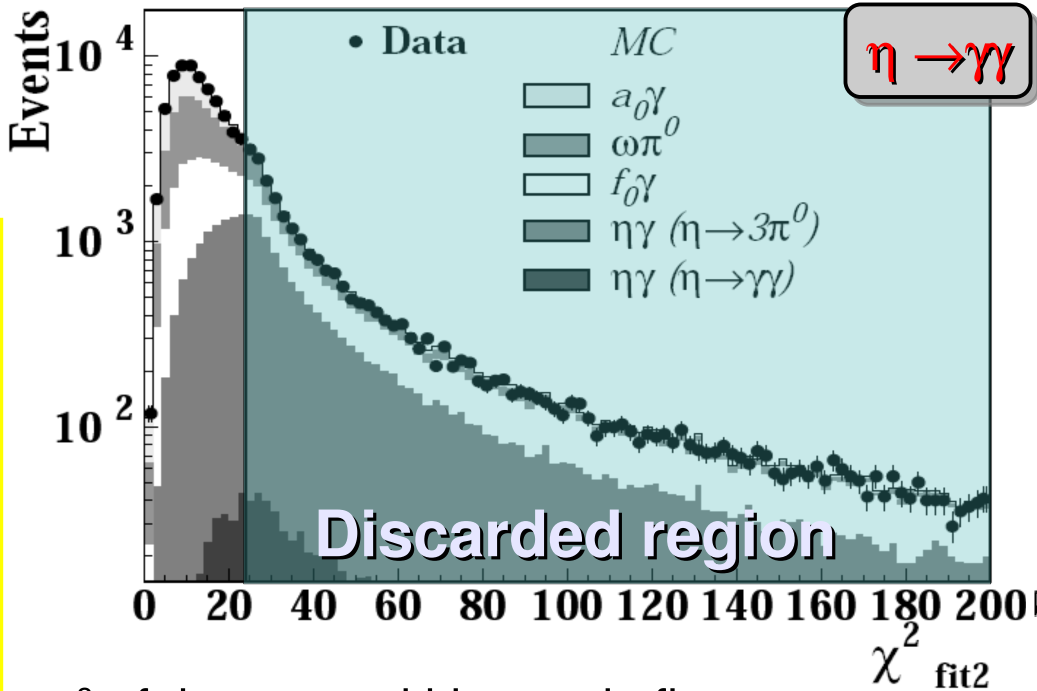
Dedicated cut on “ad-hoc” variable in background hypothesis are used especially to reject $\omega\pi^0$ and $f_0\gamma$

Event topology:
Two charged tracks forming a vertex around the IP and **five neutral clusters** with proper **energy** (>10 MeV) and **time** ($<5\sigma$)

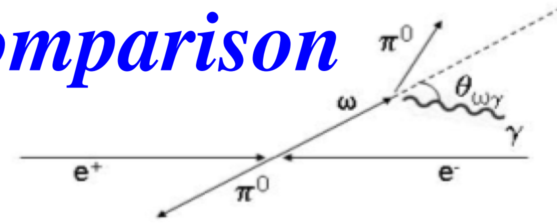
Global **kinematic fit** applied and relative χ^2 used to reject background (first only general assumption – second assuming Masses)

Events with to **low photon energy** (<20 MeV) discarded

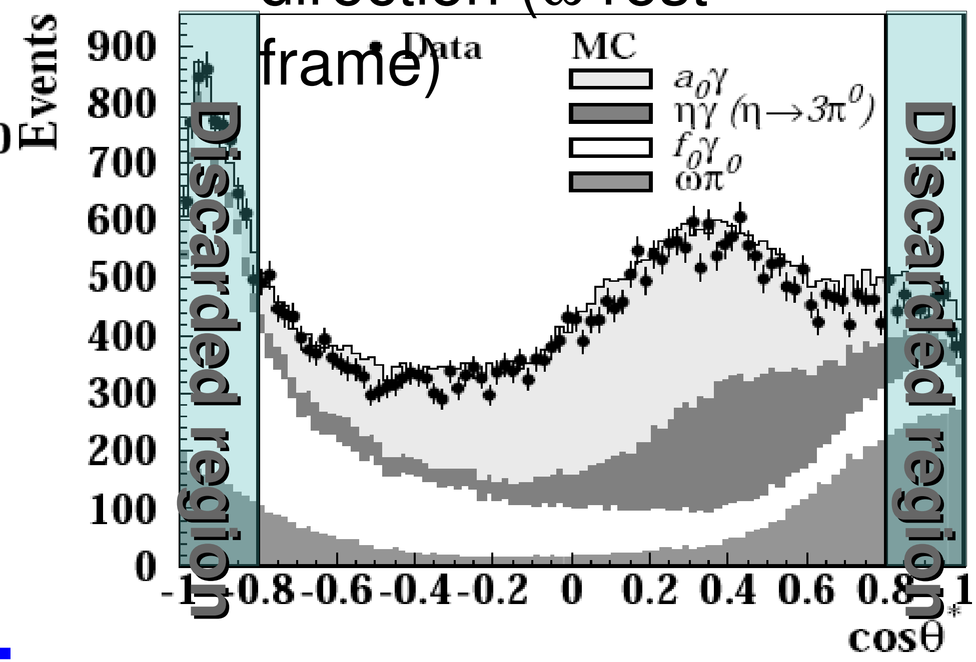
$\phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma$ Data-MC comparison



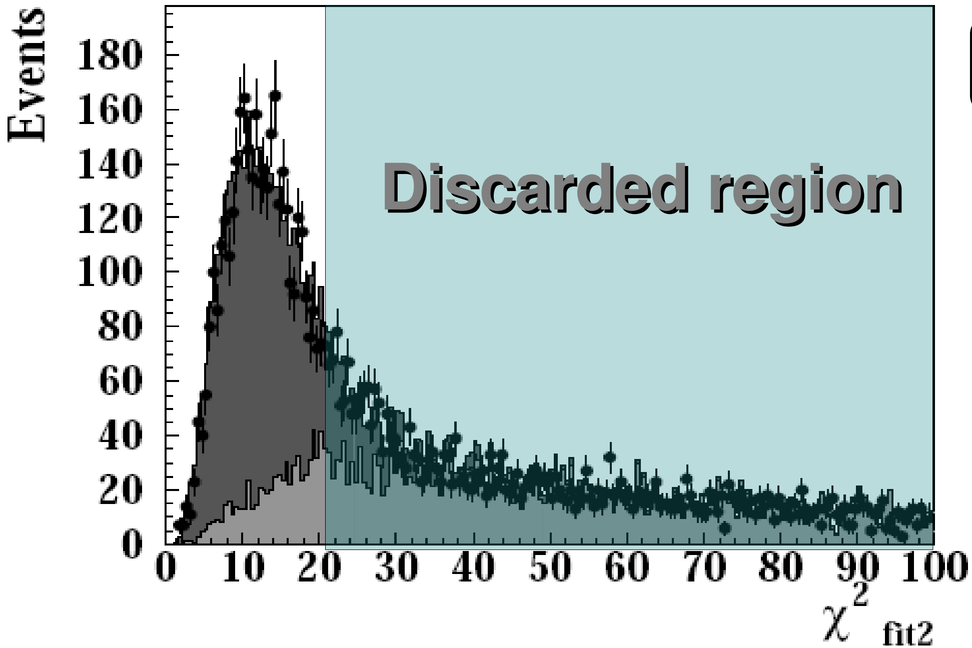
χ^2 of the second kinematic fit
In the signal hypothesis:
- η and π^0 masses imposed



Angle between photon and the "supposed" ω flight direction (ω rest frame)



$\phi \to a_0\gamma \to \eta\pi^0$ Data-MC comparison



χ^2 of the second kinematic fit

In the signal hypothesis:

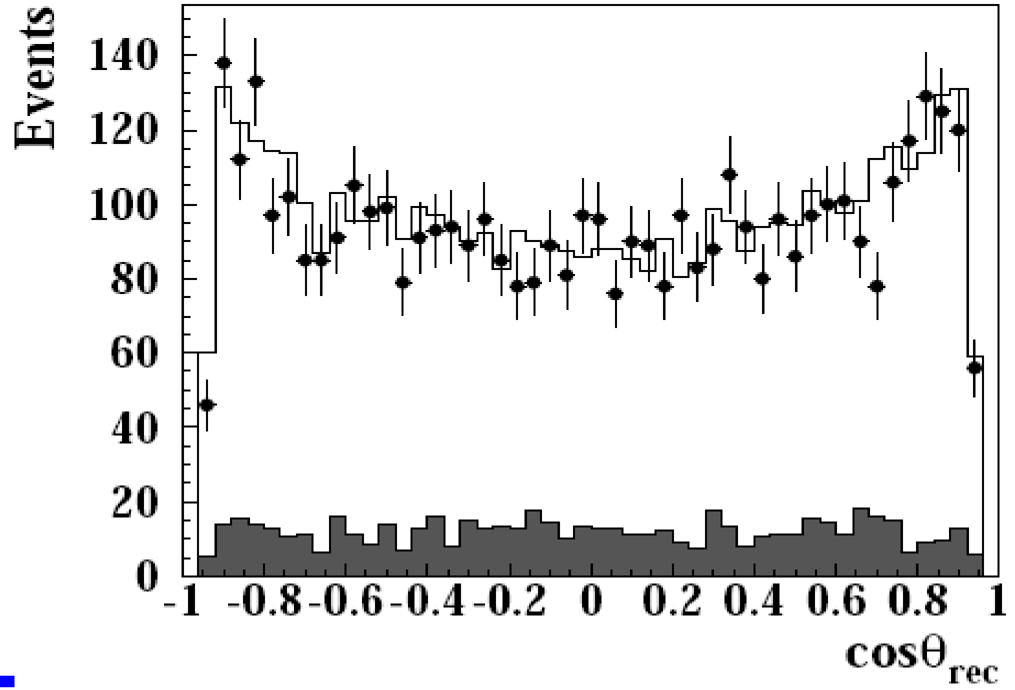
- η and π^0 masses imposed

$\eta \to \pi^+\pi^-\pi^0$

Polar angle of the "primary" photon.

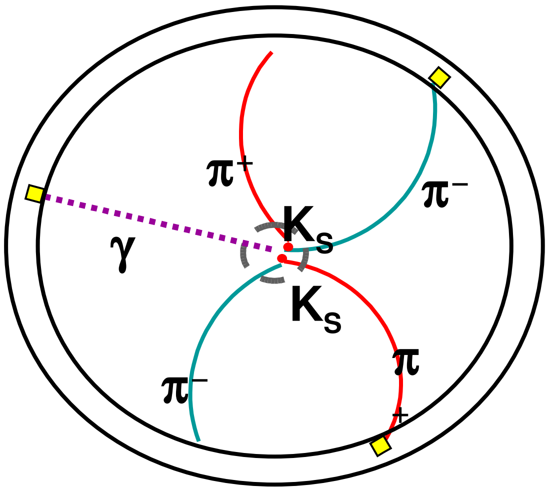
Expected distribution:

$1+\cos^2(\theta)$



$\phi \to K_S K_S \gamma$ Signal selection

Studying final state with both K_s in $\pi^+\pi^-$



Final state has:

One photon from IP

($0<E_\gamma<23.8$ MeV)

Two tracks pair from IP

KLOE Submitted to PLB

4 tracks from IP forming 2 vertices having:

$r_{vtx} < 3$ cm and $z_{vtx} < 8$ cm

Both K_S invariant mass reconstructed:

$(\Delta M_{K1})^2 + (\Delta M_{K2})^2 < (4 \text{ MeV})^2$

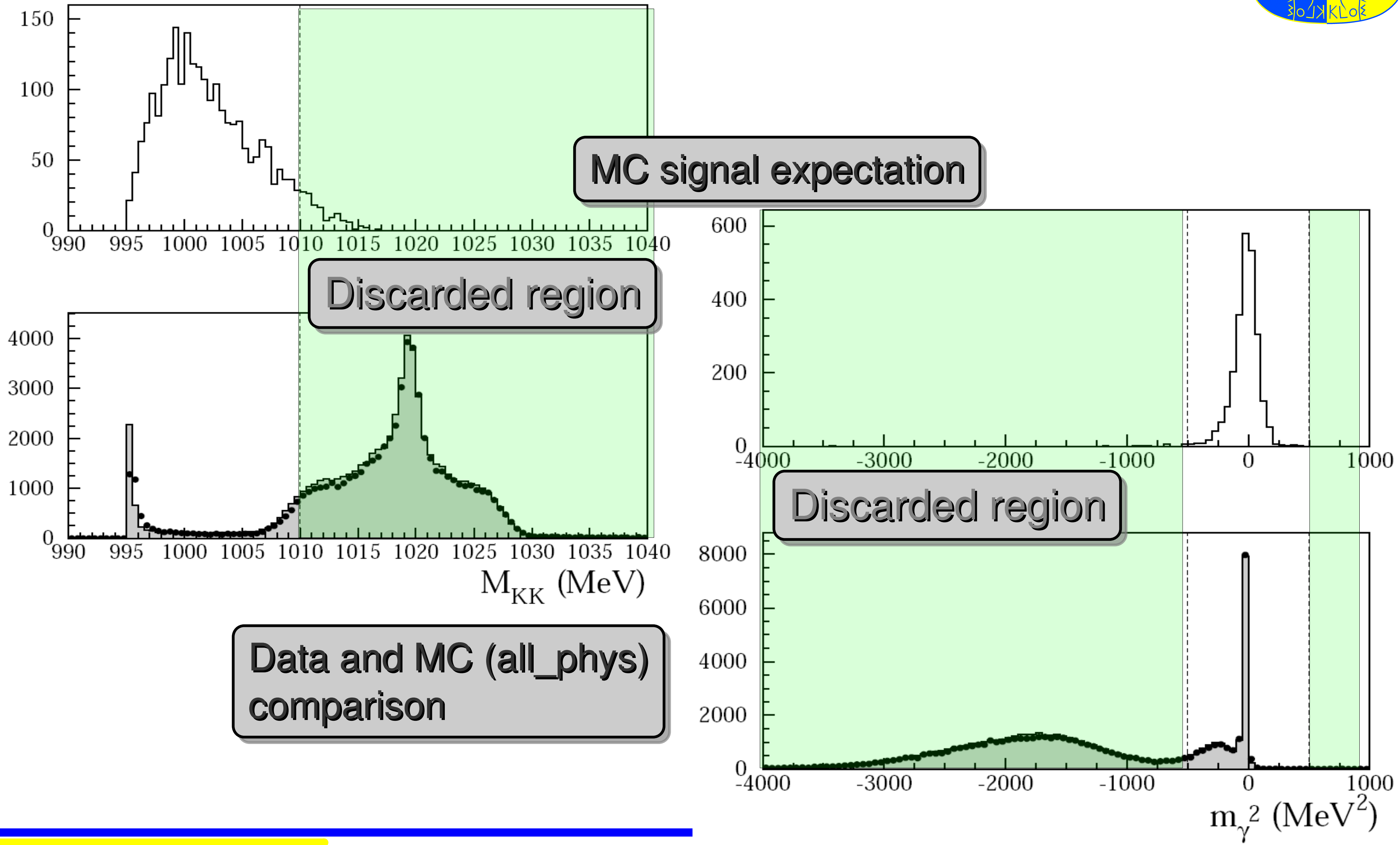
Scalar meson invariant mass:

$M_{\pi\pi\pi\pi} < 1010$ MeV

Missing mass should be zero:

$|(M_\gamma)^2| < 500 \text{ MeV}^2$

$\phi \rightarrow K_S K_S \gamma$ Data – MC comparison



Pseudoscalars

$\eta \rightarrow \pi^+\pi^- e^+ e^-$ Signal selection

Data sample: 1.7 fb^{-1}

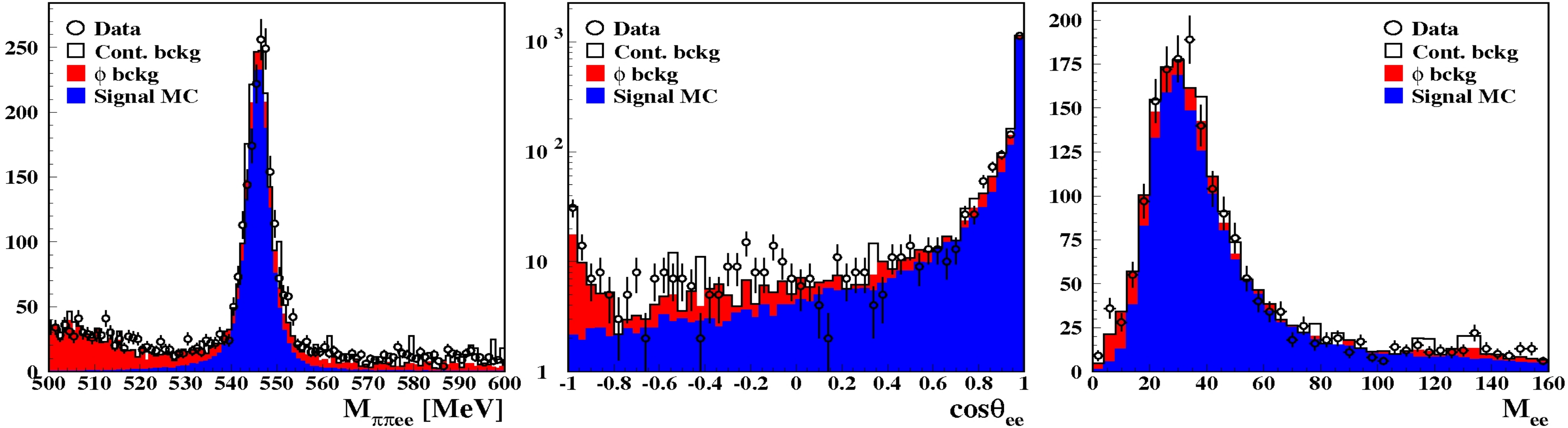
PID using TOF from EMC info

Fit to $M_{\pi\pi ee}$ sidebands for background scale factors

Photon conversion on Beam Pipe rejected

Counting on $M_{\pi\pi ee}$ in the signal region: **$N_{\pi\pi ee}$ = 1555 ± 52**

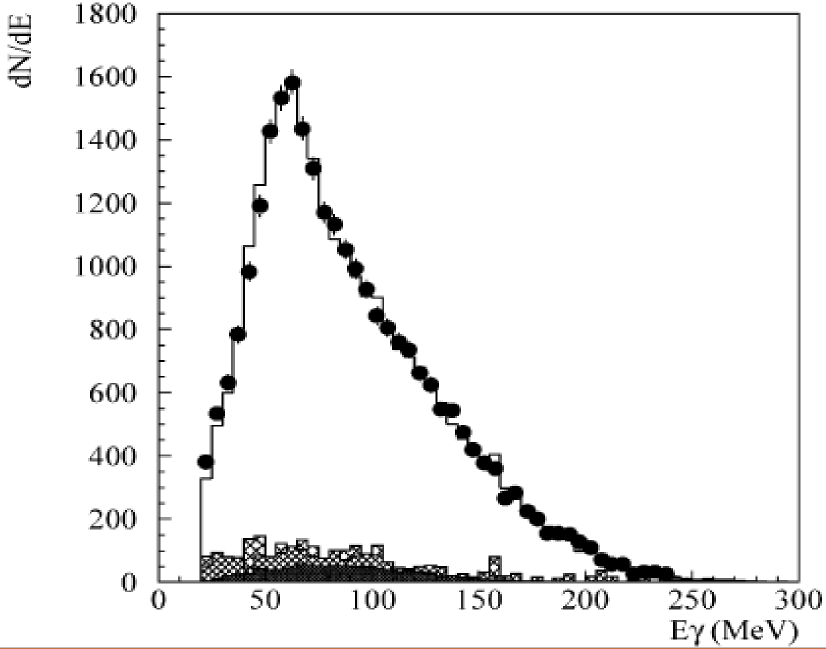
Analysis efficiency ~8% 368 bckg events

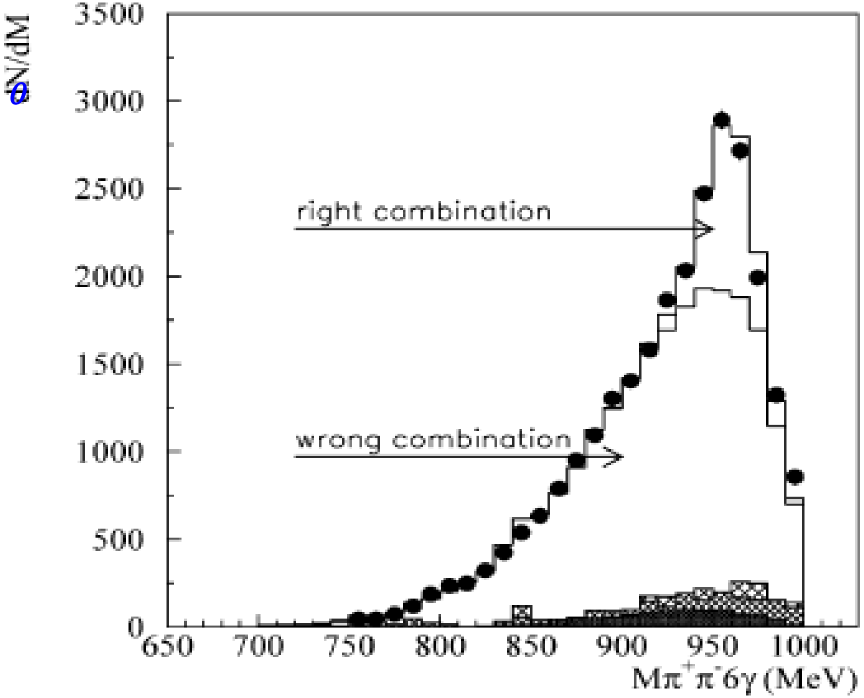


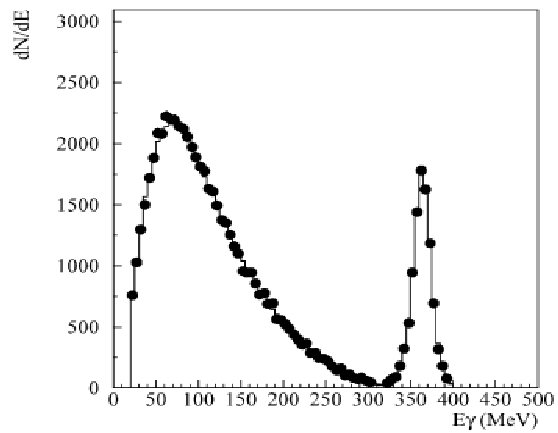
R_ϕ measurement

KLOE PLB 648 (2007)

- $\phi \to \eta' \gamma \quad \eta' \to \pi^+ \pi^- \eta \quad \eta \to 3\pi^0$
- $\phi \to \eta' \gamma \quad \eta' \to \pi^0 \pi^0 \eta \quad \eta \to \pi^+ \pi^- \pi^0$
- $\phi \to \eta \gamma \quad \eta \to 3\pi^0$



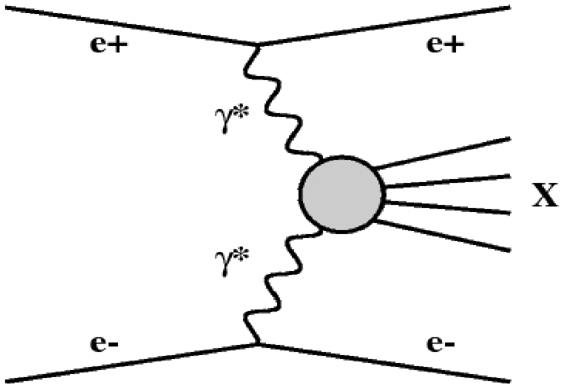




$$R_\phi = \frac{BR(\phi \to \eta' \gamma)}{BR(\phi \to \eta \gamma)} = 4.77 \pm 0.09 \pm 0.19$$

$\gamma\gamma$ physics

Search for $e^+e^- \to X \to \pi^0\pi^0$



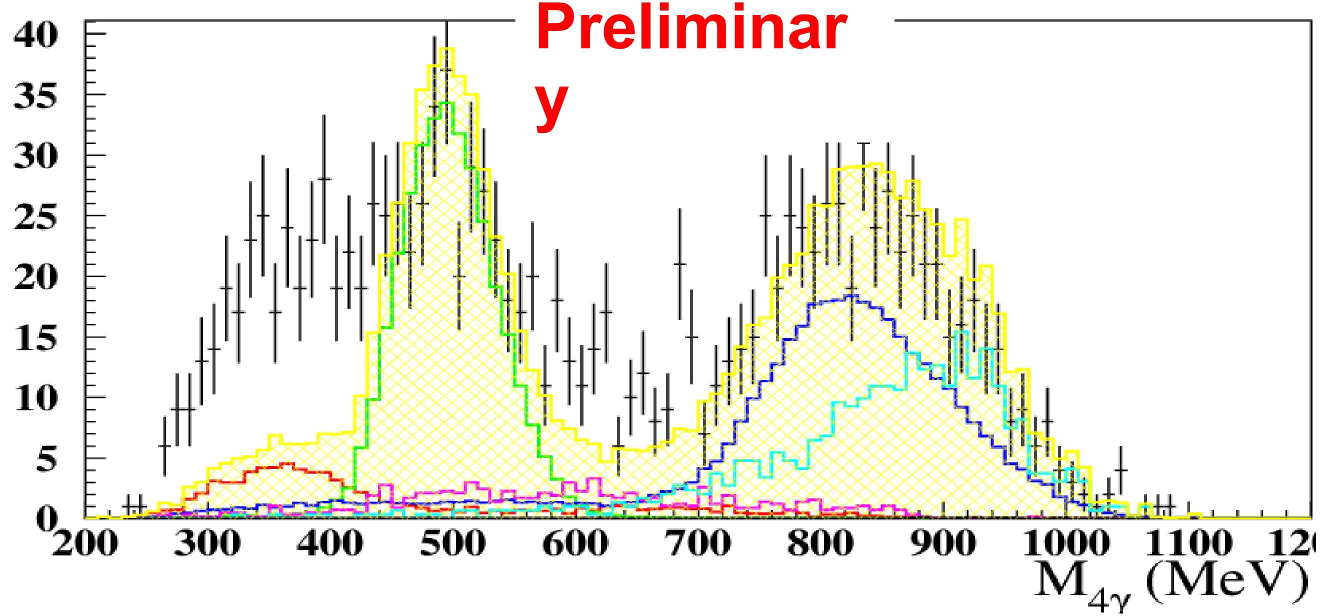
11 pb-1 @ √s = 1 GeV (~240 pb^{-1} available)

Fit to data using only background components

χ^2 / dof = 441 / 94

Excess of events wrt known background

- Total bckg
- $\phi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$
- $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$
- $\phi \to K_SK_L$
- $\phi \to f_0\gamma$
- $e^+e^- \to \gamma\gamma$

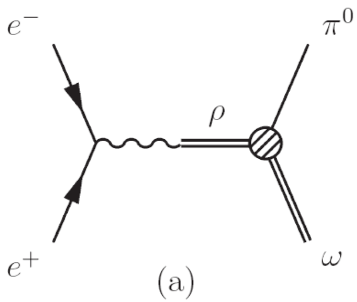


Cross sections

$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3}\int ds\,\sigma(e^+e^- \to \pi^+\pi^-)K(s)$$

$$s\frac{d\sigma_{\pi\pi}}{dM_{\pi\pi}^2} = \sigma_{\pi\pi} \times H(s)$$

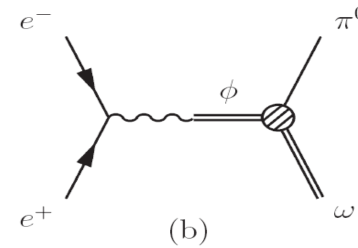
$e^+e^- \to \omega\pi^0$ Signal selection

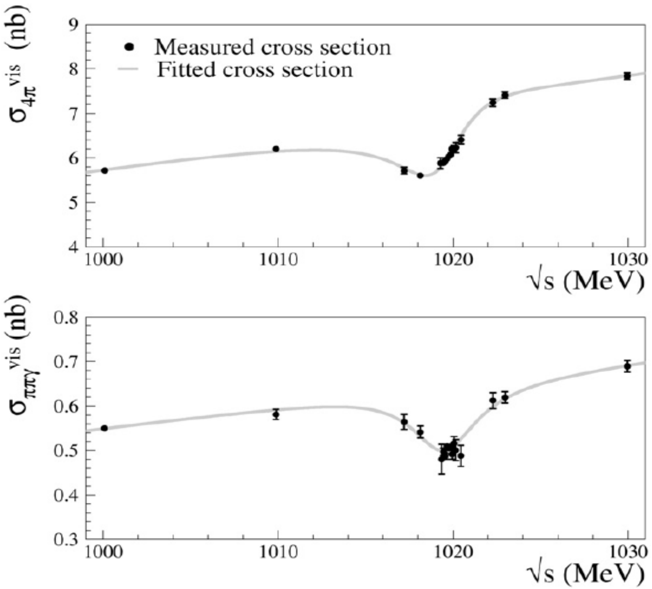


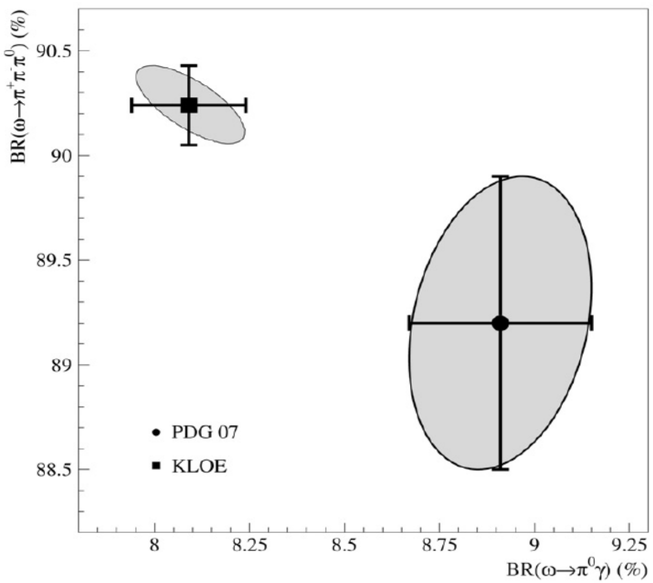
Cross section assuming only ρ / ρ' contribution(a)

Interference weighted by the ϕ meson propagator(b)

$$\sigma(E) = \sigma_0(E)\left|1 - Z\frac{m_\phi \Gamma_\phi}{D_\phi}\right|^2$$







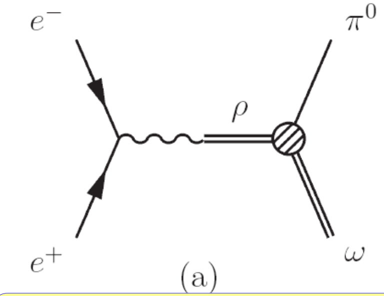
KLOE PLB669(2008)223

$$BR(\phi \to \omega\pi^0) = (4.6 \pm 0.6) \times 10^{-5}$$

$$BR(\omega \to \pi^+\pi^-\pi^0) = (90.24 \pm 0.19)\%$$

$$BR(\omega \to \pi^0\gamma) = (8.09 \pm 0.14)\%$$

$e^+e^- \to \omega\pi^0$ Signal selection

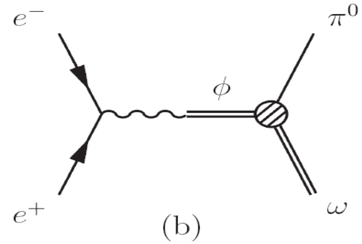


KLOE PLB669(2008)223

Cross section assuming only ρ / ρ' contribution(a)

Interference weighted by the φ meson propagator(b)

$$\sigma(E) = \boxed{\sigma_0(E)} \left| 1 - \boxed{Z \frac{m_\phi \Gamma_\phi}{D_\phi}} \right|^2$$



Cross section as a function of the √s for two different final states:

$\pi^+\pi^-\pi^0\pi^0$

- Only one vertex at Interaction Point
- Only two tracks connected at vertex
- Four neutral cluster with:
  - E_{clu} greater than 10 *MeV*
  - *ToF* compatible with prompt γ (Tw =4σ$_t$)
  - 22°< θ < 158°

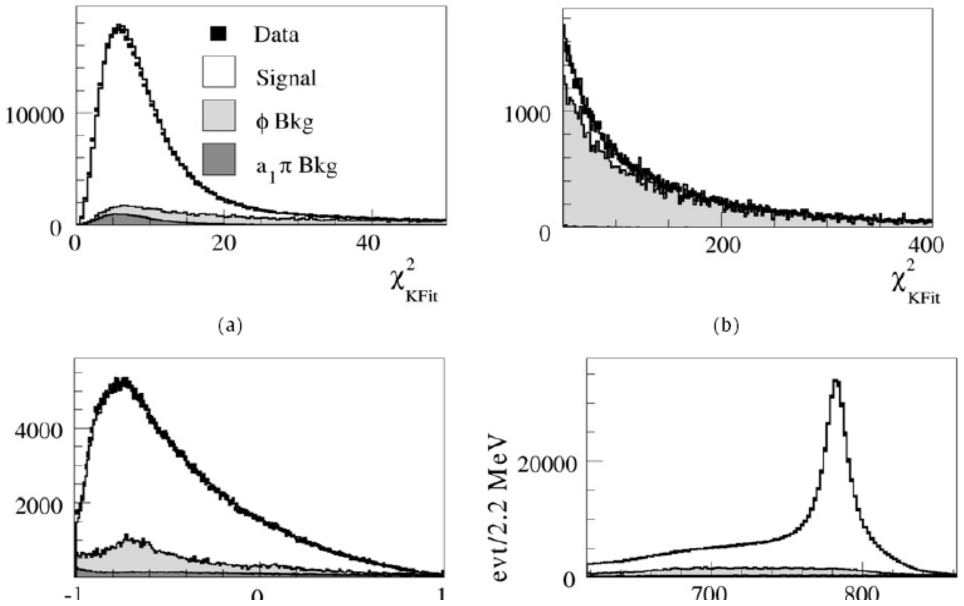
$\pi^0\pi^0\gamma$

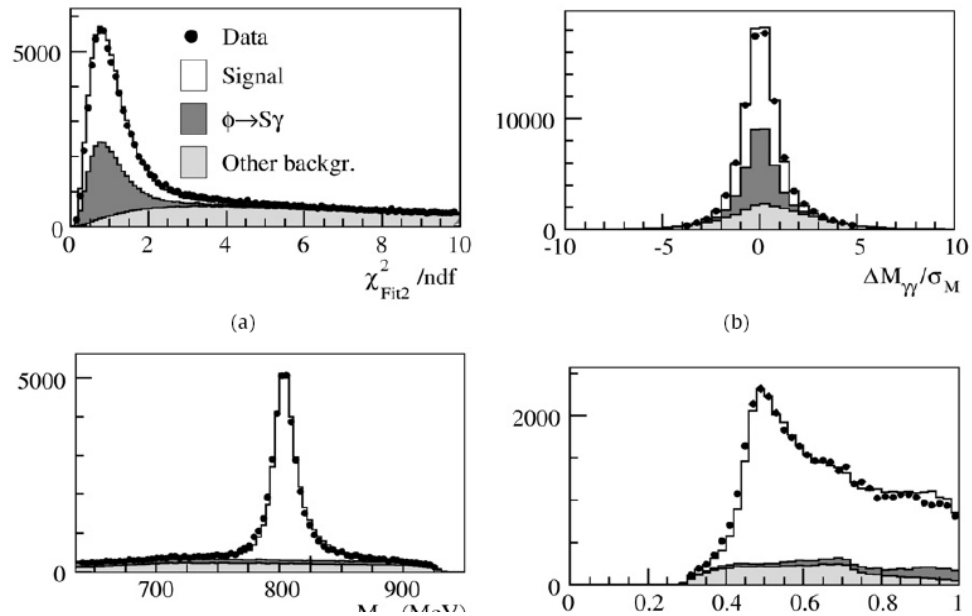
- Five neutral cluster with:
  - E_{clu} greater than 7 *MeV*
  - *ToF* compatible with prompt γ (Tw =3s$_\tau$)
  - 22°< θ < 158°

$e^+e^- \to \omega\pi^0$ Data – MC comparison

$\pi^+\pi^-\pi^0\pi^0$

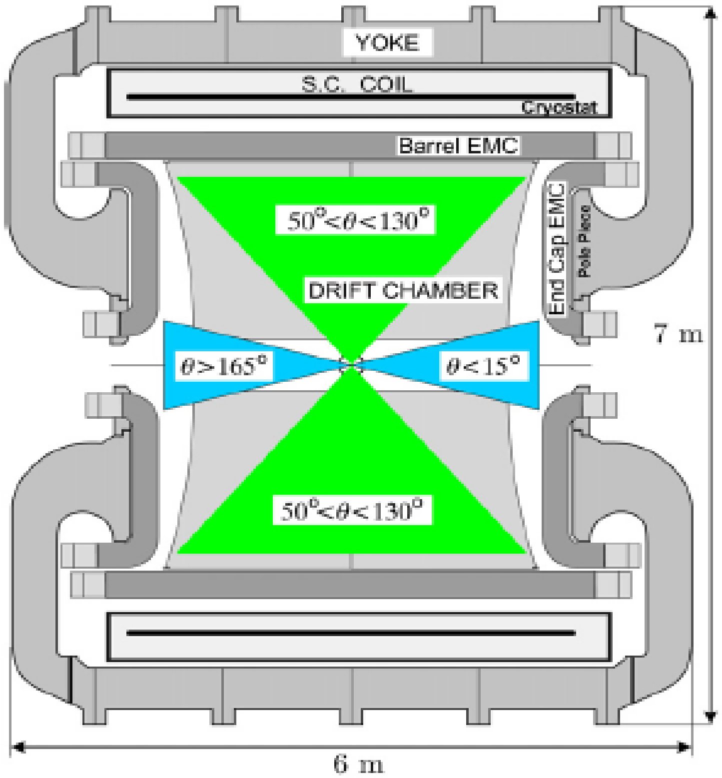
$\pi^0\pi^0\gamma$





Parameter	$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$	$e^+e^- \to \pi^0\pi^0\gamma$
σ_0 [nb]	$7.89 \pm 0.06 \pm 0.07$	$0.724 \pm 0.010 \pm 0.003$
$\Re e(Z)$	$0.106 \pm 0.007 \pm 0.004$	$0.011 \pm 0.015 \pm 0.006$
$\Im m(Z)$	$-0.103 \pm 0.004 \pm 0.003$	$-0.154 \pm 0.007 \pm 0.004$
σ' [nb/MeV]	$0.064 \pm 0.003 \pm 0.001$	$0.0053 \pm 0.0005 \pm 0.0002$

$e^+e^- \to \pi^+\pi^-\gamma$ Signal definition



Small angle: $\theta_{\pi\pi} < 15^o$ or $\theta_{\pi\pi} > 165^o$

Higher cross section (21 nb vs 3 nb)

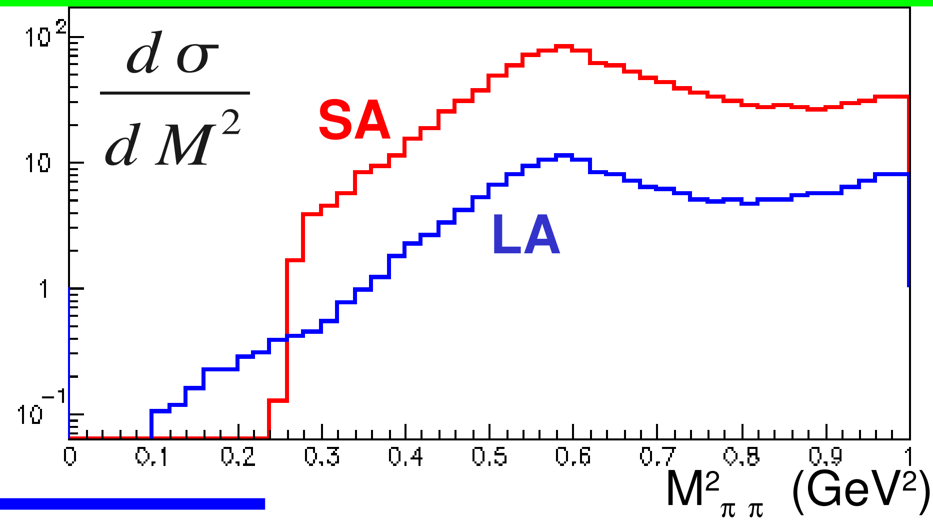
Less background

Kinematically limited

Large angle: $50^o < \theta_\gamma < 130^o$

Higher background (FSR + $\phi \to \pi^+\pi^-\pi^0 / f_0\gamma$)

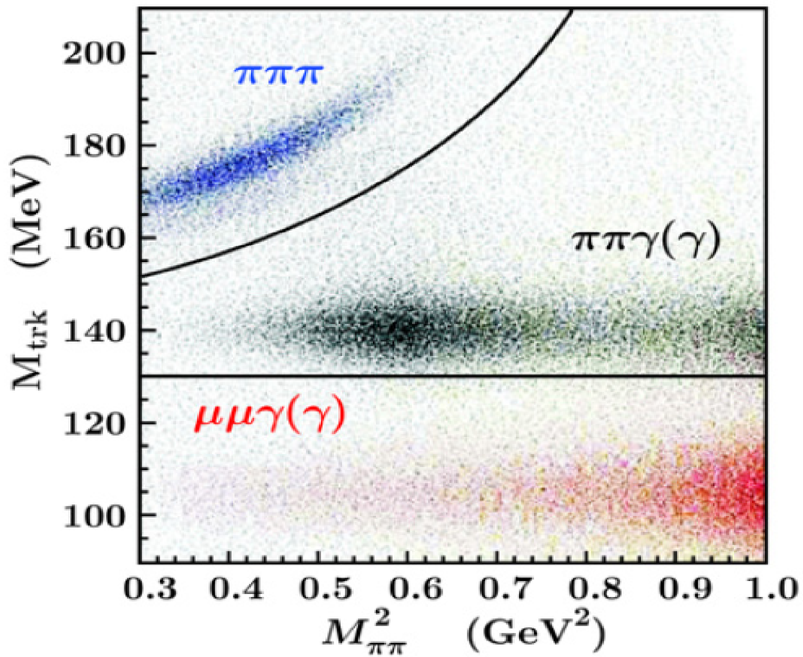
All $M_{\pi\pi}$ spectrum



$e^+e^- \to \pi^+\pi^-\gamma$ Signal selection

$$\frac{d\sigma_{\pi\pi\gamma(\gamma)}}{dM^2_{\pi\pi}} = \frac{\Delta N_{Obs} - \Delta N_{Bkg}}{\Delta M^2_{\pi\pi}} \frac{1}{\varepsilon_{sel}} \frac{1}{\int L\,dt}$$

Background rejection with PID using EMC info (*ee*γ/μμγ) and kin. cuts (φ→πππ)



Efficiencies mostly evaluated on data with two independent methods

Luminosity from Bhabha scattering events with 55°<θ<125° [EPJC47(2006)589]

[Generator used for σ_{eff}: BABYAGA (NPB758(2006)22)]

Future perspective KLOE-2

KLOE-2 Step 0

Two electron taggers proposed:

LET

Low Energy tagger

$130\ \text{MeV} < E_e < 230\ \text{MeV}$

HET

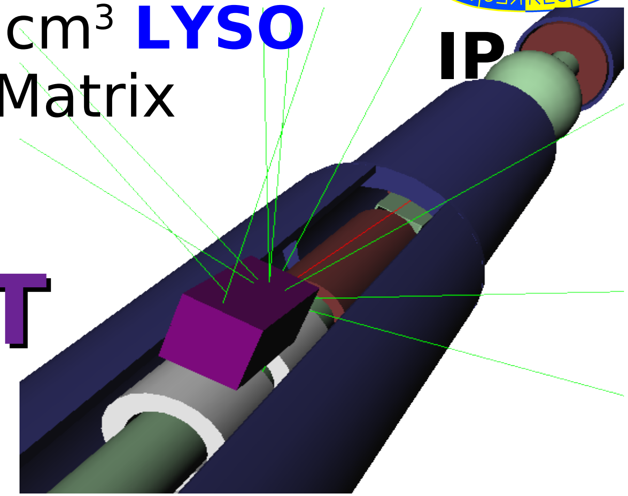
High Energy tagger

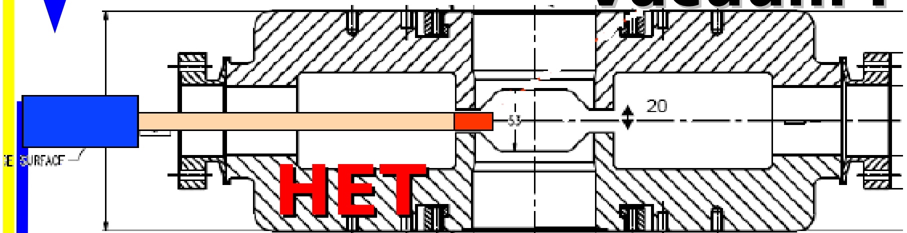
$430\ \text{MeV} < E_e < 470\ \text{MeV}$

EM Calorimeter

$2\text{x}2\text{x}13\text{cm}^3$ **LYSO**

Cristal Matrix





Plastic Scintillator

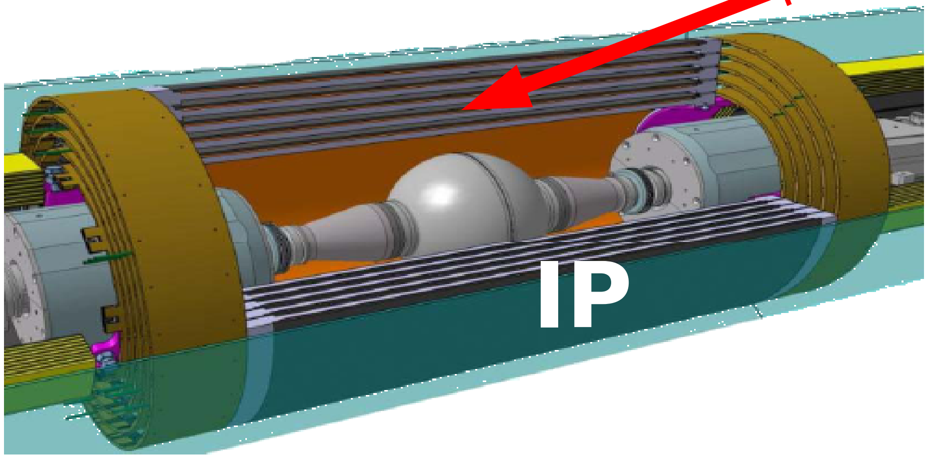
Hodoscope

$e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- (\pi^0, \sigma, \eta, \ldots)$

Tagger coincidence ensure kinematic closure together with main KLOE detector

KLOE-2 Step 1

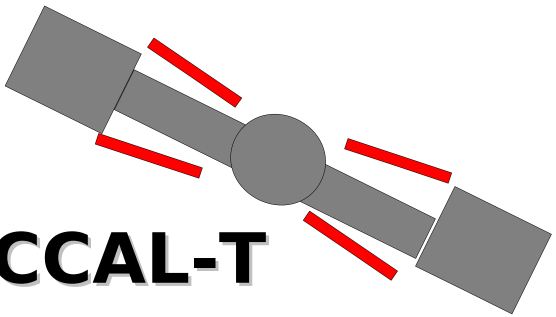
TRIPLE Cylindrical GEM



Inner Tracker

5 GEM planes
Min radius: 13 cm
Max radius: 25 cm
$\sigma_{xy} \sim 200\mu m$ $\sigma_z \sim 500\ \mu m$
Material budget: **0.2 X_0**

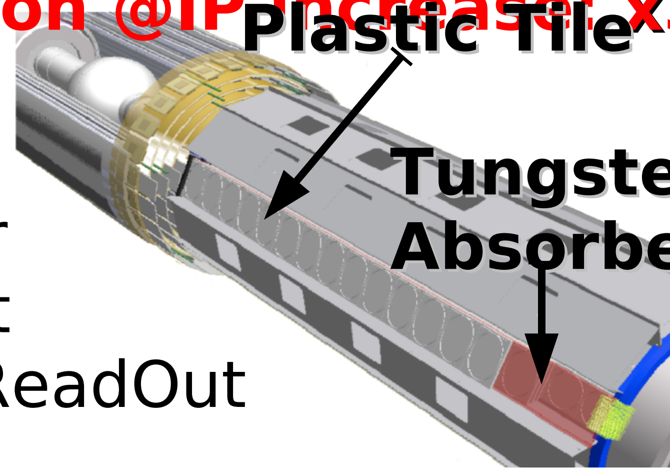
Vertex resolution @IP increase: x3



CCAL-T

LYSO Cristal
Pointing geometry
LOW θ acceptance

QCAL-T



1m cylinder
12 segment
Single tile ReadOut
with fiber
Photon impact point resolution increase: x10