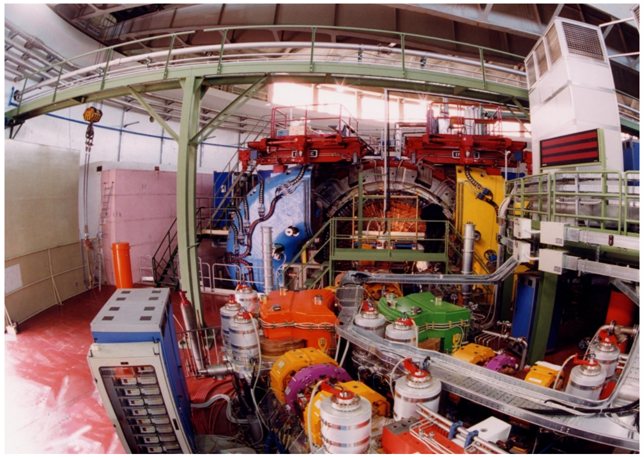
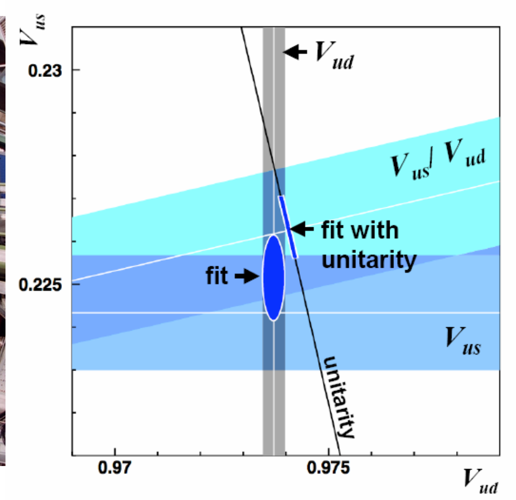
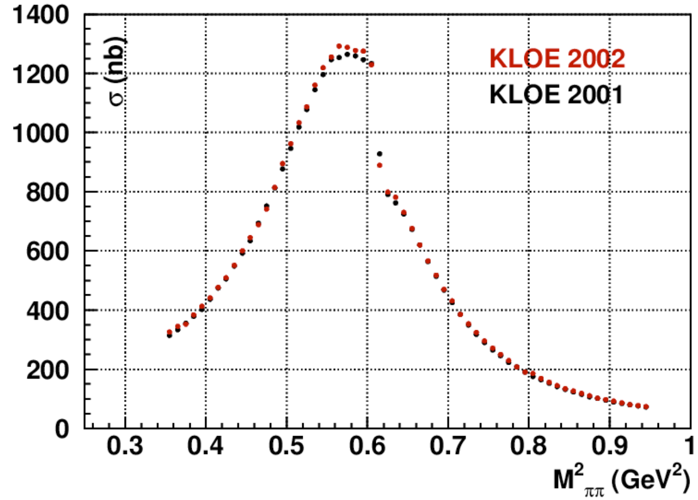
Precision Kaon and Hadronic Physics with KLOE







Patrizia de Simone, LNF/INFN
on behalf of the KLOE Collaboration

SLAC seminar , 30 October, 2007

Outlook

KLOE results that I will discuss in some detail

Vus extraction from complete set of observables: BR's, τ's, λ's
allows the most precise test of unitarity of the CKM matrix
precise knowledge of weak coupling constant as test of NP models

LF violation tests from $V_{US}(K_{e3})/V_{US}(K_{\mu3})$ and from $\Gamma(K_{e2})/\Gamma(K_{\mu2})$
NP with LFV can give % effects wrt SM prediction for K_{l2} decays

two new analyses for $\sigma(e^+e^- \to \pi\pi)$
fundamental input to SM evaluation of the muon anomaly a_μ

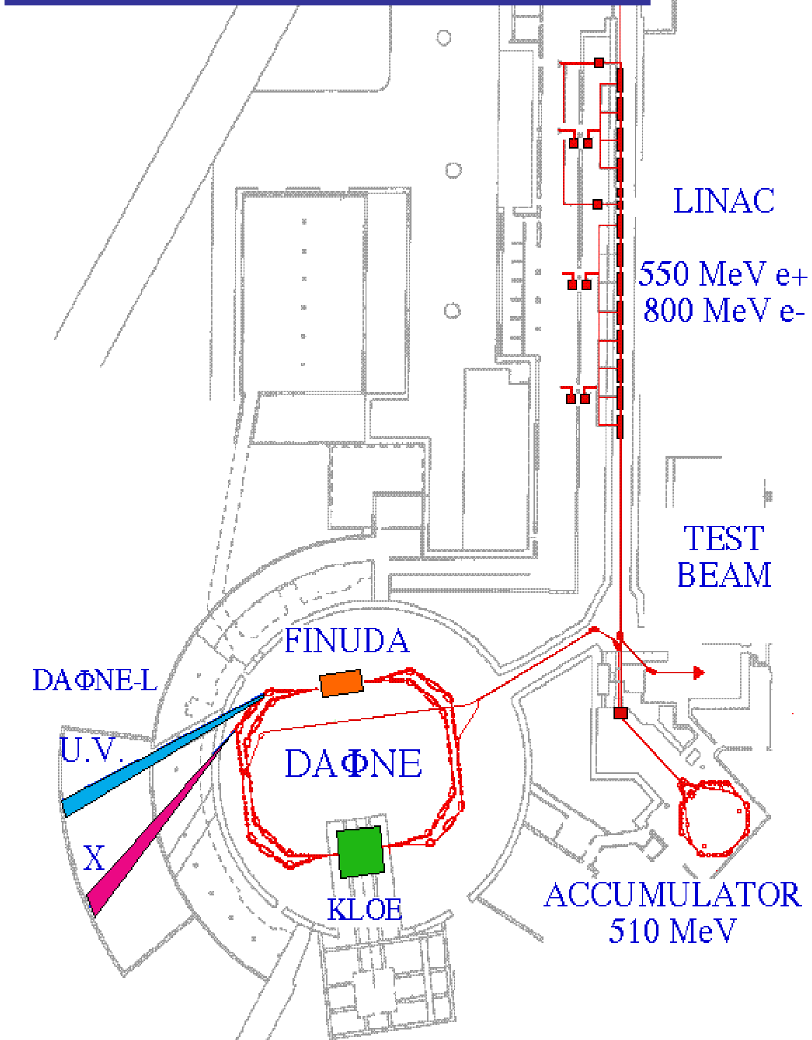
light meson spectroscopy
study of the nature of the $f_0(980)$ and $a_0(980)$ in $\pi\pi\gamma$ and $\eta\pi^0\gamma$ final states

I will also touch on

rare K_S decays
CPT invariance test via the Bell Steinberger relation
Quantum Mechanics test
η and η' mesons decays

DaΦne: the frascati ϕ factory

$\mathcal{L}_{design}$ = 5×10^{32} cm^{-2} s^{-1}



- e+e- collider @ $\sqrt{s}$ = **1019.4 MeV**
- separate e+, e- rings to minimize beam-beam interactions
- crossing angle: 12.5 mrad (2001/02) 15 mrad (2004/05)
- time between collision 2.7 ns
- injection during data-taking

Daϕne performances in 2004/05

$\cong$ 105 $e^+ + e^-$ bunches

$I^-_{peak}\sim 2.4$ A, $I^+_{peak}\sim 1.5$ A

$\underline{\mathcal{L}_{peak} = 1.4 \times 10^{32}\ cm^{-2}\ s^{-1}}$

$\mathcal{L}_{avg}$ month $\cong$ 200 pb^{-1}

Kaon production

the ϕ decay at rest provides monochromatic and pure kaon beams

the KK pairs in the final state have the same quantum numbers as the ϕ, *i.e.*, they are produced in a pure $J^{PC} = 1^{--}$ state

$\sigma(e^+e^- \to \phi) \approx 3\ \mu b$ $K_S, K^+ \longleftarrow \phi \longrightarrow K_L, K^-$

detection of a K_S (K_L) guarantees the presence of a K_L (K_S) with known momentum and direction (the same for K^+K^-) $\Rightarrow$ **tagging**

pure kaon beam obtained $\Rightarrow$ normalization (N_{tag}) sample

$\Rightarrow$ allows precision measurements of absolute BRs

K^+K^-

BR $\cong$ 49%

p_{lab} = 127 MeV/c

$\lambda_\pm$ = 95 cm

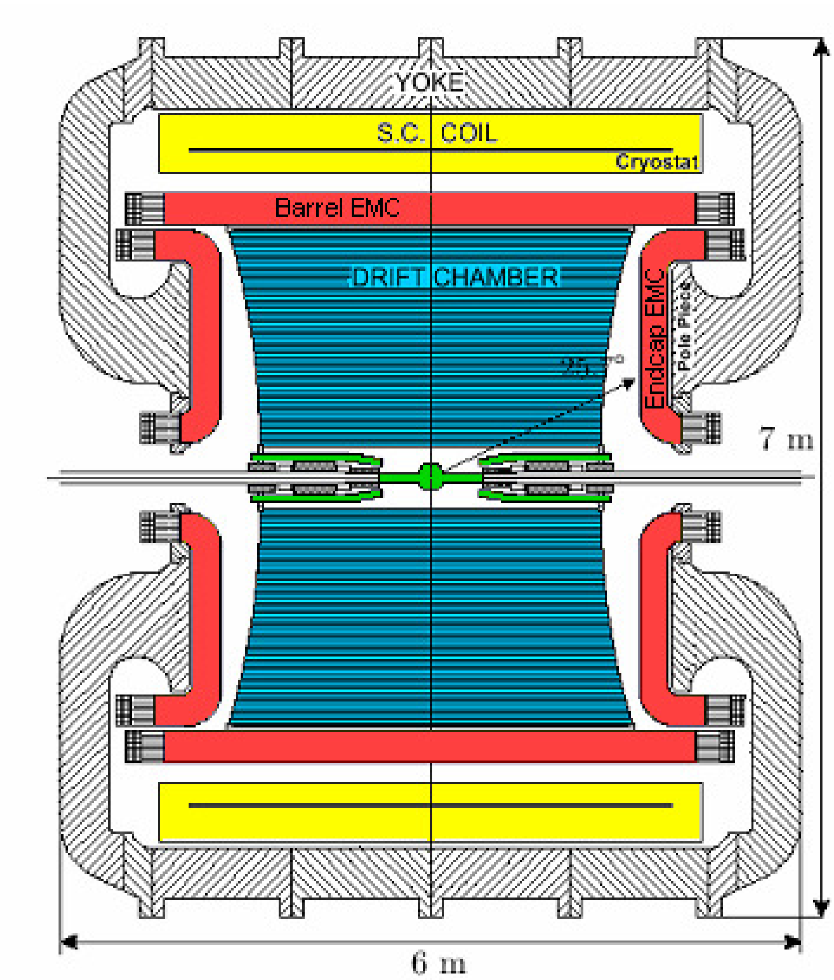
K_LK_S

BR $\cong$ 34% ; p_{lab} = 110 MeV/c

λ_S = 0.6 cm K_S decays near interaction point

λ_L = 340 cm Large detector to keep reasonable acceptance for K_L decays (~0.5 λ_L)

The KLOE experiment



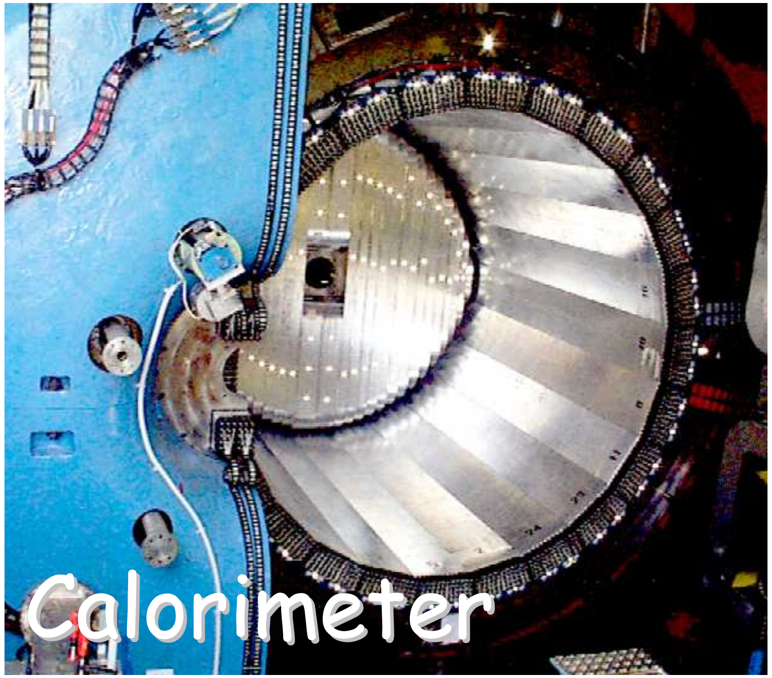
Be beam pipe (0.5 mm thick),
r =10 cm (K_S fiducial volume)
Instrumented permanent magnet quadrupoles (32 PMT's)

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

Electromagnetic calorimeter
Lead/scintillating fibers
4880 PMT's, cover 98% of the solid angle

Superconducting coil
B = 0.52 T ($\int Bdl$ = 2 T·m)

KLOE detector performance



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

$\sigma_t \cong 57$ ps $/\sqrt{E(GeV)} \oplus 140$ ps
(relative time between clusters)

$\sigma_{\gamma\gamma} \sim 2$ cm (π^0 from $K_L \to \pi^+\pi^-\pi^0$)

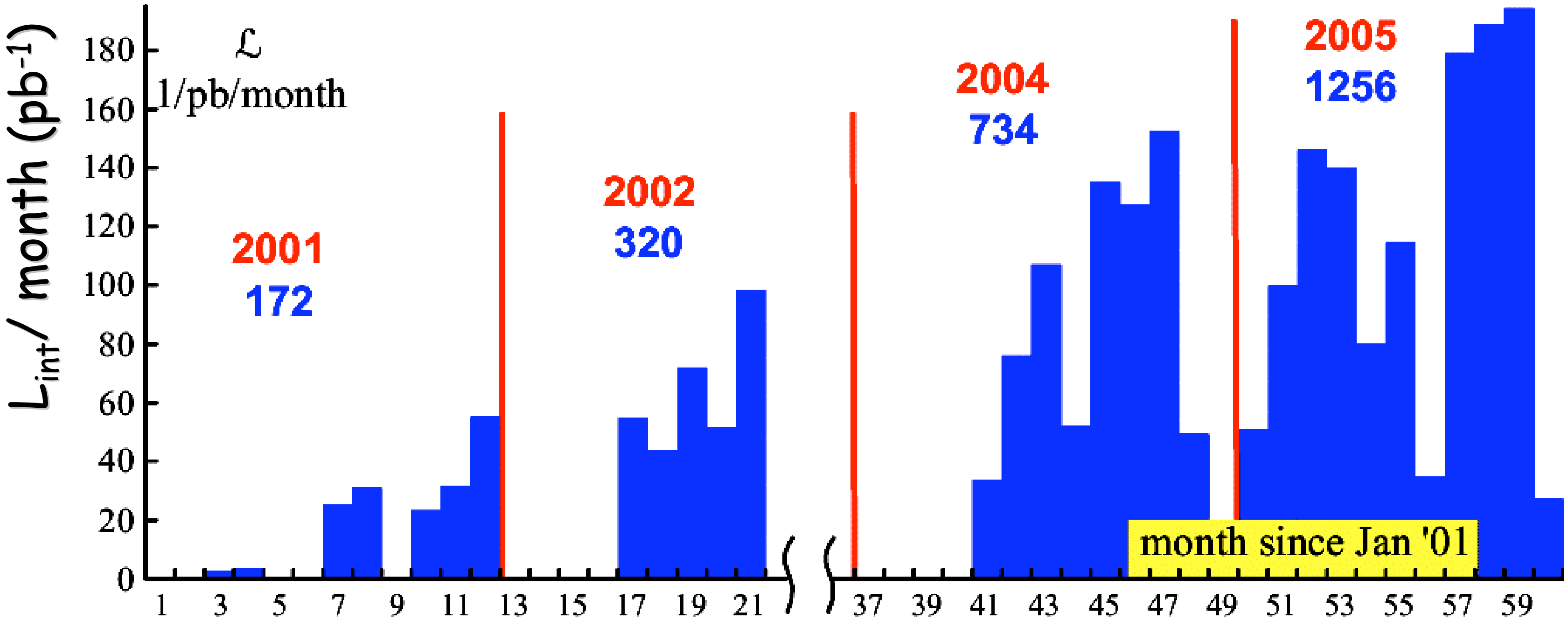
$\sigma_p/p \cong 0.4$ % (tracks with $\theta > 45°$)

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

$\sigma_x^{vertex} \sim 3$ mm

The KLOE data sample

data taking for KLOE experiment, years 2001-2005, now run completed



2001-5 ~2.5 fb^{-1} integrated @ $\sqrt{s}=M(\phi)$, yielding ~2.5 x 10^9 K_SK_L and ~ 3.6 x 10^9 K^+K^- pairs

2006 4-pt energy scan around ϕ peak + 225 pb^{-1} off peak data, $\sqrt{s}$=1GeV

Kaon Physics

V_{us}	Absolute BR's for $K^{\pm}_{l3}$	ArXiv:0707.2532
	K^{+} lifetime	ArXiv:0705.4408
	Absolute BR for $K^{+} \to \pi^{+}\pi^{0}$	ArXiv:0707.2654
	Scalar form factor slope for $K_{L\mu3}$	ArXiv:0707.4631
LFV	$\Gamma(K^{\pm} \to e\nu)/\Gamma(K^{\pm} \to \mu\nu)$*	ArXiv:0707.4623
χPT	$BR(K_S \to \gamma\gamma)$*	ArXiv:0707.3933
	$d\Gamma(K_L \to \pi e \nu \gamma)/dE_{\gamma}$	ArXiv:0707.4634
	$UL(K_S \to e^{+}e^{-})$*	ArXiv:0707.2687
CPT	Bell-Steinberger	JHEP 0612:011 → CPT review in PDG'07
QM	$K_S K_L$ interferometry*	preliminary at KAON

* whole data sample

$V_{us}f_{+}(0)$ & V_{us}/V_{ud} @ KLOE

Interest for V_{us} meaurement with kaons

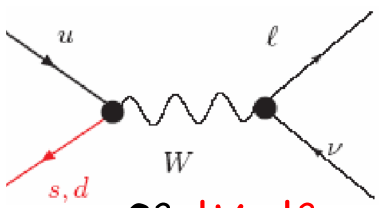
in SM, universality of weak coupling dictates

$$G_{CKM}^2 = (|V_{ud}|^2 + |V_{us}|^2)\, G_F^2 \text{ (from } \mu \text{ lifetime)} = (g_w/M_w)^2 \quad [V_{ub} \text{ negligible}]$$

we can test for possible breaking of the conditions

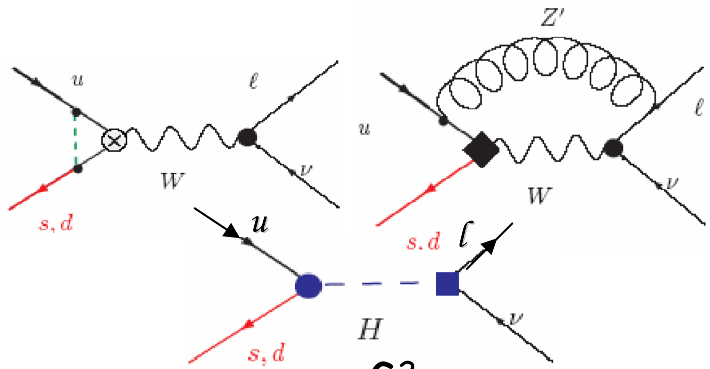
<u>CKM unitarity</u> $(|V_{ud}|^2 + |V_{us}|^2) = 1$ <u>Universality</u> $G_{CKM}^2 = (|V_{ud}|^2 + |V_{us}|^2)\, G_F^2$

Standard Model



$\propto G_F^2 |V_{uq}|^2$

+



$\propto G_F^2\, \varepsilon$

$\varepsilon \sim 10^{-3}$

$\varepsilon \sim 10^{-2}$

New Physics

<u>G_{CKM} = 1.16XX(04) x10^{-5} GeV^{-2} → V_{us} at 0.5%</u> makes CKM unitarity test with kaons competitive to Electro-Weak precision test [$G_{e.w.}$ = 1.1655(12)x10^{-5} GeV^{-2}]

reference value G_F = 1.166371(6)x10^{-5} GeV^{-2} (from μ lifetime)

V_{us} from semileptonic kaon decays

$$\Gamma(K \to \pi l \nu(\gamma)) = |V_{us}|^2 \, |f_+^{K\pi}(0)|^2 \, \frac{G_F^2 m_K^5}{768\,\pi^3} \, S_{ew} \, C_K^2 \, I_K^l(\lambda'_+, \lambda''_+, \lambda_0) \, (1 + \delta_K^l)$$

theoretical inputs

✓ $f_+(0)$ form factor at zero momentum transfer ➔ purely theoretical calculation, recent result from UKQCD/RBC $f_+(0) = 0.961(5)$ in agreement with Leutwyler and Roos $f_+(0) = 0.961(8)$

✓ $\delta_K^l = (\Delta_K^{SU(2)} + \Delta_K^{l\,em})$ e.m. and I-breaking corr., presently known @ few ‰ level

✓ S_{EW} universal short distance electroweak corr. $S_{ew} = 1.0232$,
$C_K = 1$ ($2^{-1/2}$) for K^0 ($K^{\pm}$) decays

experimental inputs

✓ $I_K^l(\lambda'_+, \lambda''_+, \lambda_0)$ phase space integral, $\lambda'_+, \lambda''_+, \lambda_0$, denote the t-dependence of vector and scalar form factors

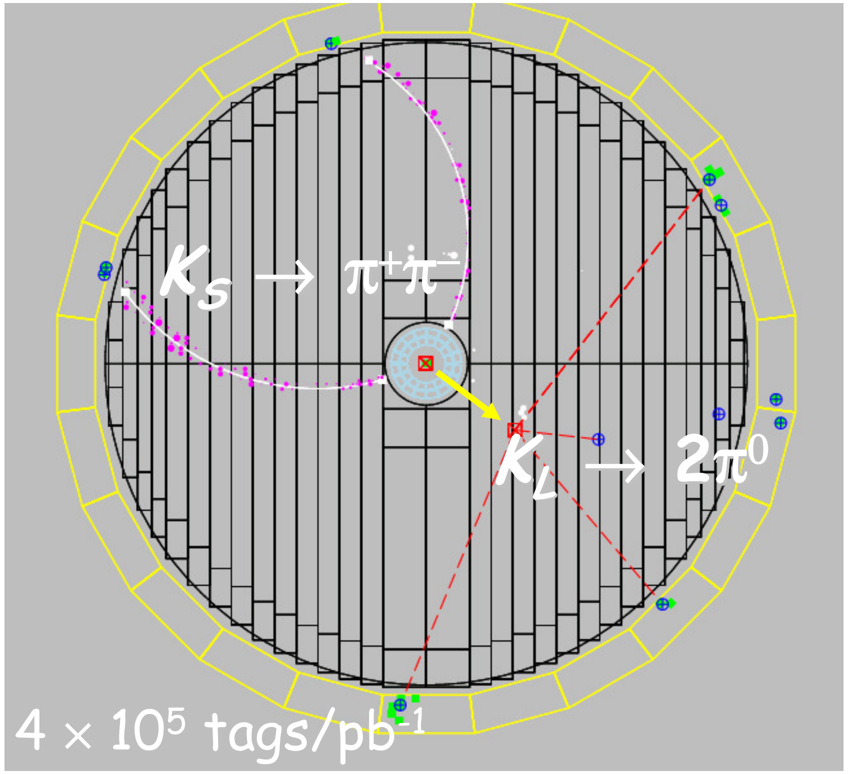
✓ $\Gamma K_{l3(\gamma)}$ semileptonic decay widths, evaluated from γ-inclusive BR's and lifetimes

✓ m_K appropriate kaon mass

KLOE is measuring all the relevant inputs: BR's, lifetimes, ff's

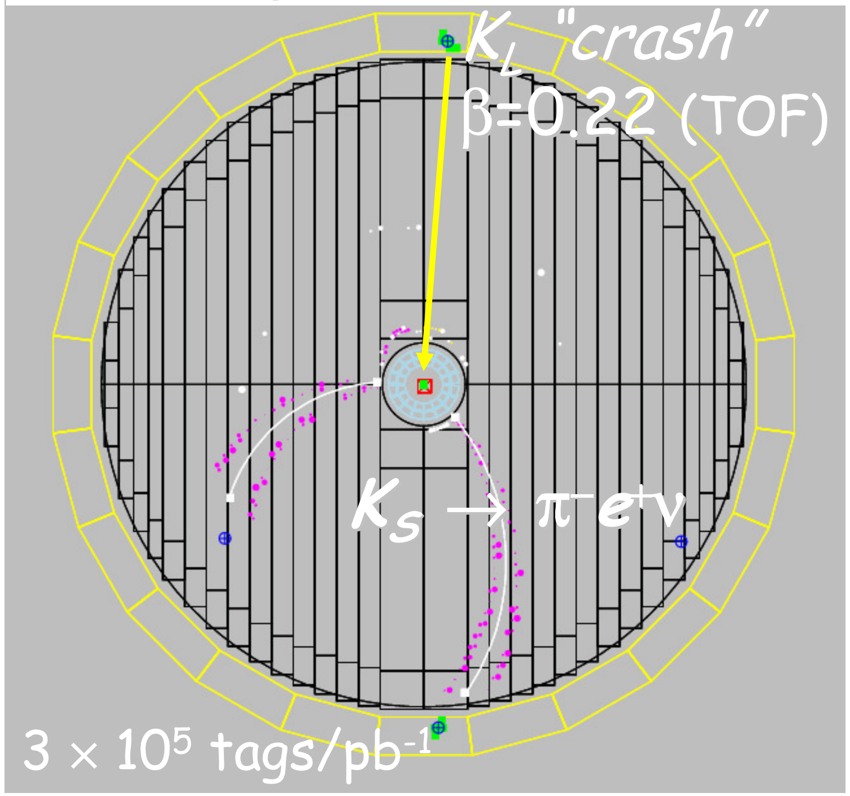
Tagging of K_L K_S beams

K_L tagged
by $K_S \to \pi^+\pi^-$ vertex at IP



ε ~ **70%** (mainly geometrical)
K_L angular resolution: ~ 1°
K_L momentum resolution: ~ 1 MeV

K_S tagged
by K_L interaction in EmC



ε ~ **30%** (mainly geometrical)
K_S angular resolution: ~ 1° (0.3° in ϕ)
K_S momentum resolution: ~ 1 MeV

Analysis of $K_S \to \pi e \nu$

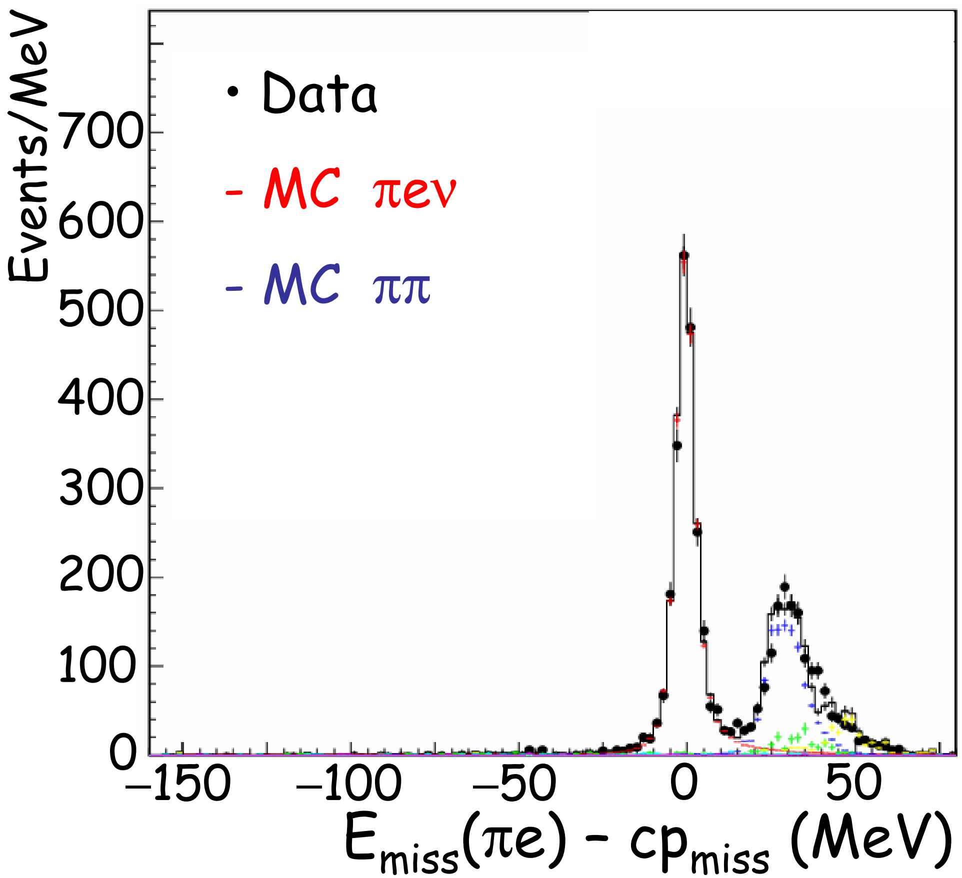
event selection (410 pb^{-1})

- K_S tagged by K_L crash
- two tracks from IP to EmC
- kinematic cuts to reject background from $K_S \to \pi\pi$
- track-cluster association required

e/π ID from TOF identifies charge of final state

number of signal counts by fitting data to a linear combination of MC spectra for signal and background (MC includes radiative processes)

normalize signal counts to $K_S \to \pi\pi(\gamma)$ counts in the same data set (use PDG04 for $BR(K_S \to \pi\pi(\gamma))$, dominated by KLOE measurement)



$K_S \to \pi e \nu$: results

unique to KLOE

[PLB 636(2006)]

$BR(K_S \to \pi^- e^+ \nu) = (3.528 \pm 0.057 \pm 0.027) \times 10^{-4}$

$BR(K_S \to \pi^+ e^- \nu) = (3.517 \pm 0.051 \pm 0.029) \times 10^{-4}$

$BR(K_S \to \pi e \nu) = (7.046 \pm 0.077 \pm 0.049) \times 10^{-4}$

BR($\pi e \nu$) [KLOE '02, *Phys.Lett.B535*, 17 pb^{-1}]:$(6.91 \pm 0.34_{stat} \pm 0.15_{syst})\ 10^{-4}$

$A_S = (1.5 \pm 9.6_{stat} \pm 2.9_{syst}) \times 10^{-3}$
with 2.5 fb^{-1} KLOE can measure
A_S to 3×10^{-3}

compare to results for A_L:
KTeV $(3.322 \pm 0.058 \pm 0.047) \times 10^{-3}$
NA48 $(3.317 \pm 0.070 \pm 0.072) \times 10^{-3}$

linear form factor slope $\lambda_+ = (33.9 \pm 4.1) \times 10^{-3}$

compatible with the linear slope obtained from K_L semileptonic decays

Dominant K_L branching ratios

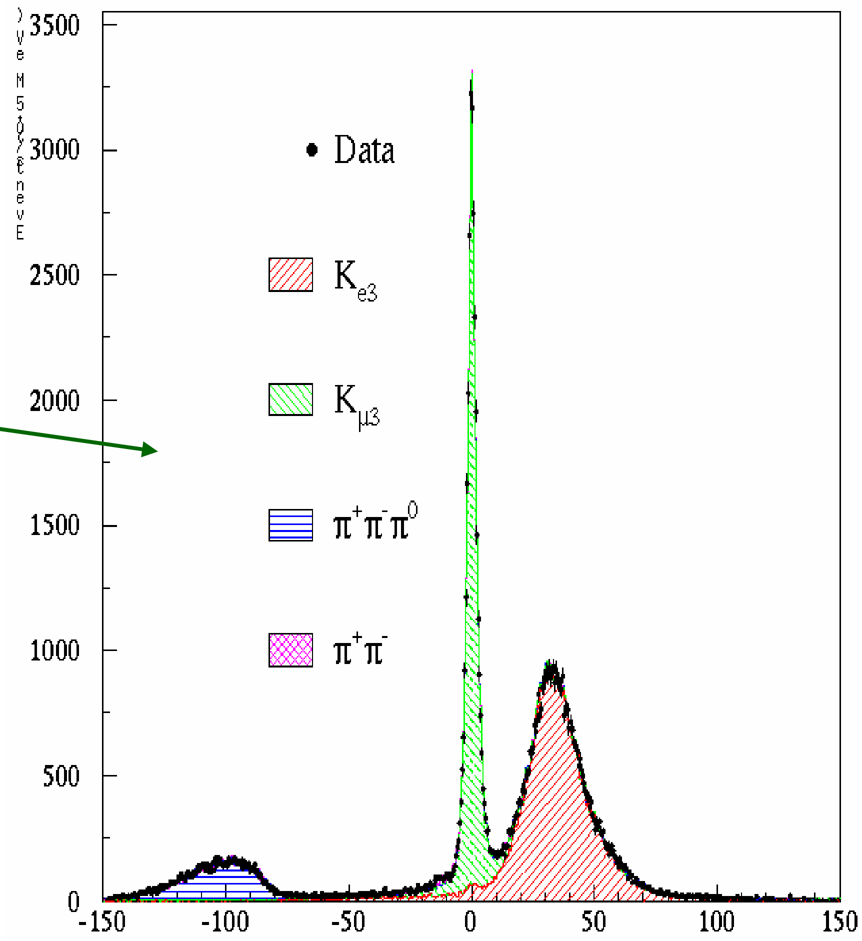
Absolute BR measurements to 0.5-1%

from 328 pb^{-1} data sample

K_L tagged by $K_S \to \pi^+\pi^-$:
- 13×10^6 for the measurement
- 4×10^6 used to evaluate efficiencies

BR's to $\pi e\nu$, $\pi\mu\nu$, and $\pi^+\pi^-\pi^0$:
- K_L vertex reconstructed in DC
- PID using decay kinematics
- fit with MC spectra including radiative processes

BR to $\pi^0\pi^0\pi^0$:
- photon vertex reconstructed by TOF using EmC (3 clusters)
- ε_{rec} = 99%, background < 1%



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

Dominant K_L BRs and K_L lifetime

using the constraint $\sum BR(K_L) = 1$ we get

$BR(K_L \to \pi e \nu(\gamma)) = 0.4007 \pm 0.0006_{stat} \pm 0.0014_{syst}$
$BR(K_L \to \pi \mu \nu(\gamma)) = 0.2698 \pm 0.0006_{stat} \pm 0.0014_{syst}$
$BR(K_L \to 3\pi^0) = 0.1997 \pm 0.0005_{stat} \pm 0.0019_{syst}$
$BR(K_L \to \pi^+\pi^-\pi^0(\gamma)) = 0.1263 \pm 0.0005_{stat} \pm 0.0011_{syst}$

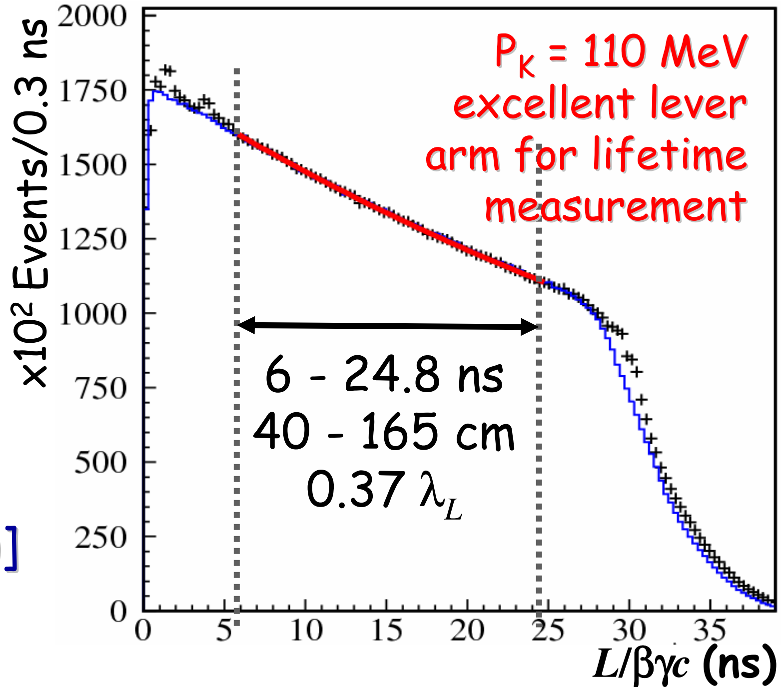
lifetime measurement
$\tau_L = 50.72 \pm 0.17 \pm 0.33$ ns
[PLB 632 (2006)]

τ_L measurement from $K_L \to \pi^0\pi^0\pi^0$, 400 pb^{-1}

- require $\geq 3\ \gamma$'s
- $\varepsilon(L_K) \sim 99\%$, uniform in L
- $\sigma_L(\gamma\gamma) \sim 2.5$ cm
- background ~ 1.3%

use $K_L \to \pi^+\pi^-\pi^0$ for
- EmC time scale
- γ vertex efficiency

lifetime measurement [PLB 626 (2005)]
$\tau_L = 50.92 \pm 0.17 \pm 0.25$ ns



KLOE average $\to \tau_L = 50.84 \pm 0.23$ ns (Vosburg, '72 $\tau_L = 51.54 \pm 0.44$ ns)

K_{Le3} form factor slopes

- 328 pb^{-1}, 2×10^6 K_{e3} decays
- PID by kinematic cuts and ToF measurements
- residual bkg reduced to 0.5% using NN trained on E/p and cluster shape
- separate measurement for each charge state ($e^+\pi^-$, π^+e^-) to check systematics
- momentum transfer t measured from π and K_L momenta: $\sigma(t/m_\pi^2) \sim 0.3$

(correlations between λ_+' and λ_+'' = - 95 %)

Linear: $1 + \lambda_+ t$ P(χ^2) =89%

$\lambda_+ = (28.6 \pm 0.5 \pm 0.4) \times 10^{-3}$

Quadratic: $1 + \lambda'_+ t/m^2_{\pi+} + 1/2\, \lambda''_+ (t/m^2_{\pi+})^2$

$\lambda'_+ = (25.5 \pm 1.5 \pm 1.0) \times 10^{-3}$

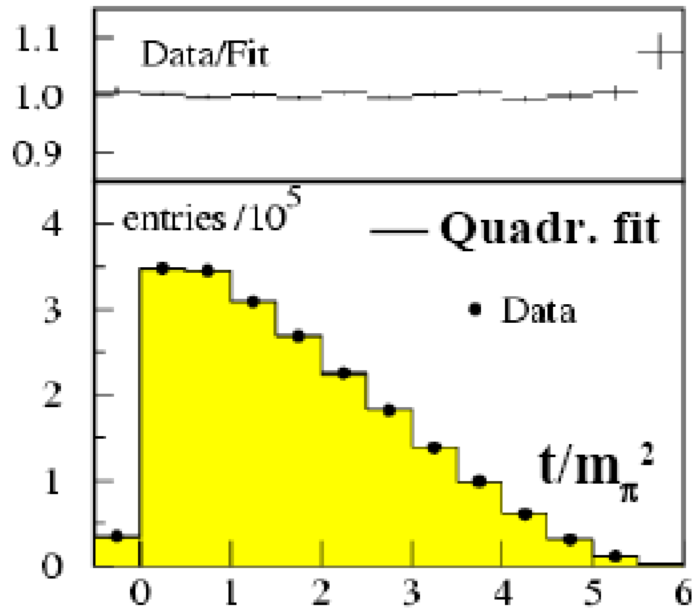
$\lambda''_+ = (1.4 \pm 0.7 \pm 0.4) \times 10^{-3}$

$\rho(\lambda'_+, \lambda''_+) = -0.95$ P(χ^2) =92%

Pole model: $M_V^2/(M_V^2 - t)$,

Taylor exp.$\Rightarrow$ $\lambda'_+ = (m_\pi/M_V)^2$, $\lambda''_+ = 2\lambda'^2_+$

$m_V = (870 \pm 7)$ MeV P(χ^2) =92.4%



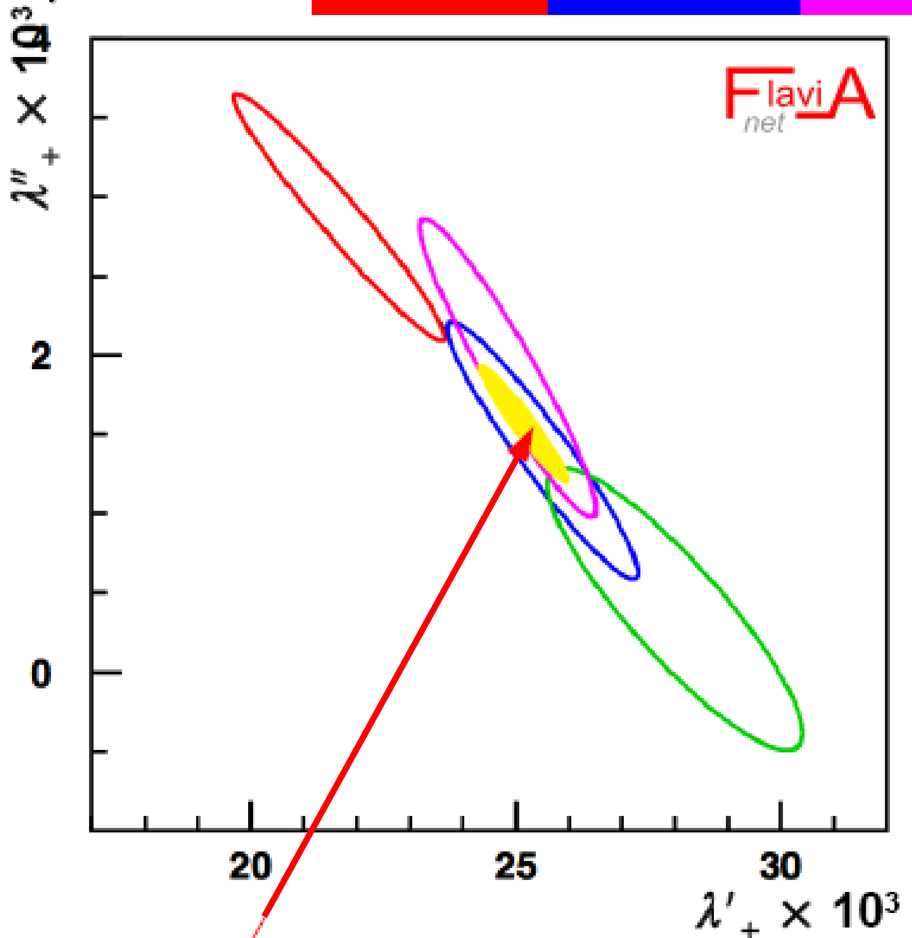
[PLB 636(2006)]

Phase space integral

Pole model versus Quadratic parameterization 0.5 per mil difference

K_{e3} slopes comparison

slopes from **KTeV** **KLOE** **ISTRA+** **NA48** **This fit**



Slope parameters × 10^3		
λ'_+	=	**25.15 ± 0.87**
λ''_+	=	**1.57 ± 0.38**
$\rho(\lambda'_+, \lambda''_+)$	=	−0.941
χ^2/ndf	=	5.3/6 (51%)

significance of $\lambda''_+ > 4\sigma$

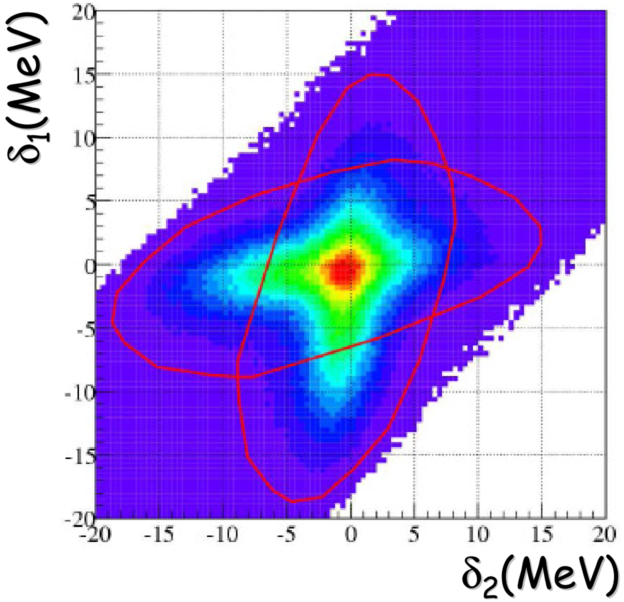
good agreement with the pole parametrization as expected from dispertion relations (Stern et al., Pich et al.)

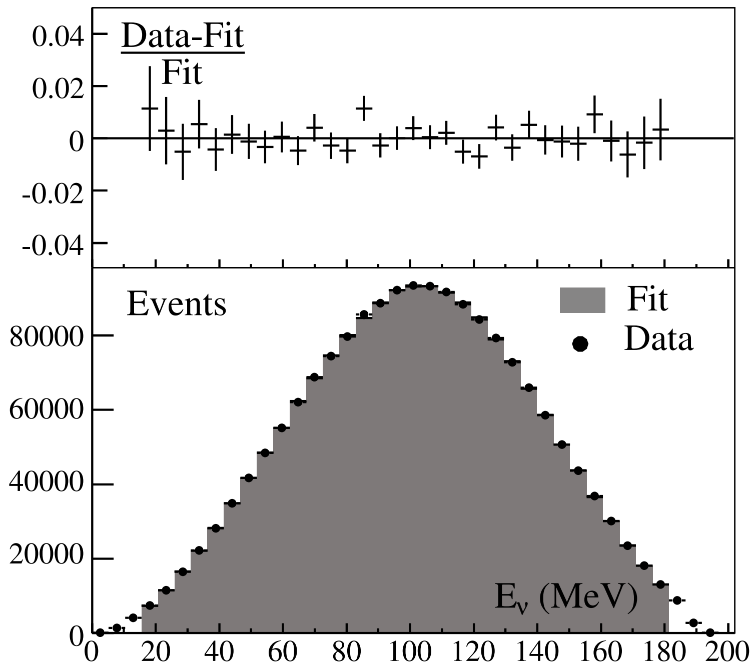
$K_{L\mu3}$ form factor slope λ_0

- K_L tagged by $K_S \to \pi^+\pi^-$
- background rejection of $\pi^+\pi^-$, $\pi^+\pi^-\pi^0$ and K_{e3} from kinematics ✓ cut on

$$\delta_1 = E_{miss}(\pi^+,\mu^-) - p_{miss}$$
$$\delta_2 = E_{miss}(\pi^-,\mu^+) - p_{miss}$$

- background contamination reduced to 1.5% using TOF measurements & NN trained on E/p and cluster shape





π/μ ID with ToF is difficult at low energies

λ_0 slope by fitting the E_ν distribution, and combined fit with K_Le3 results for λ'_+ and λ''_+

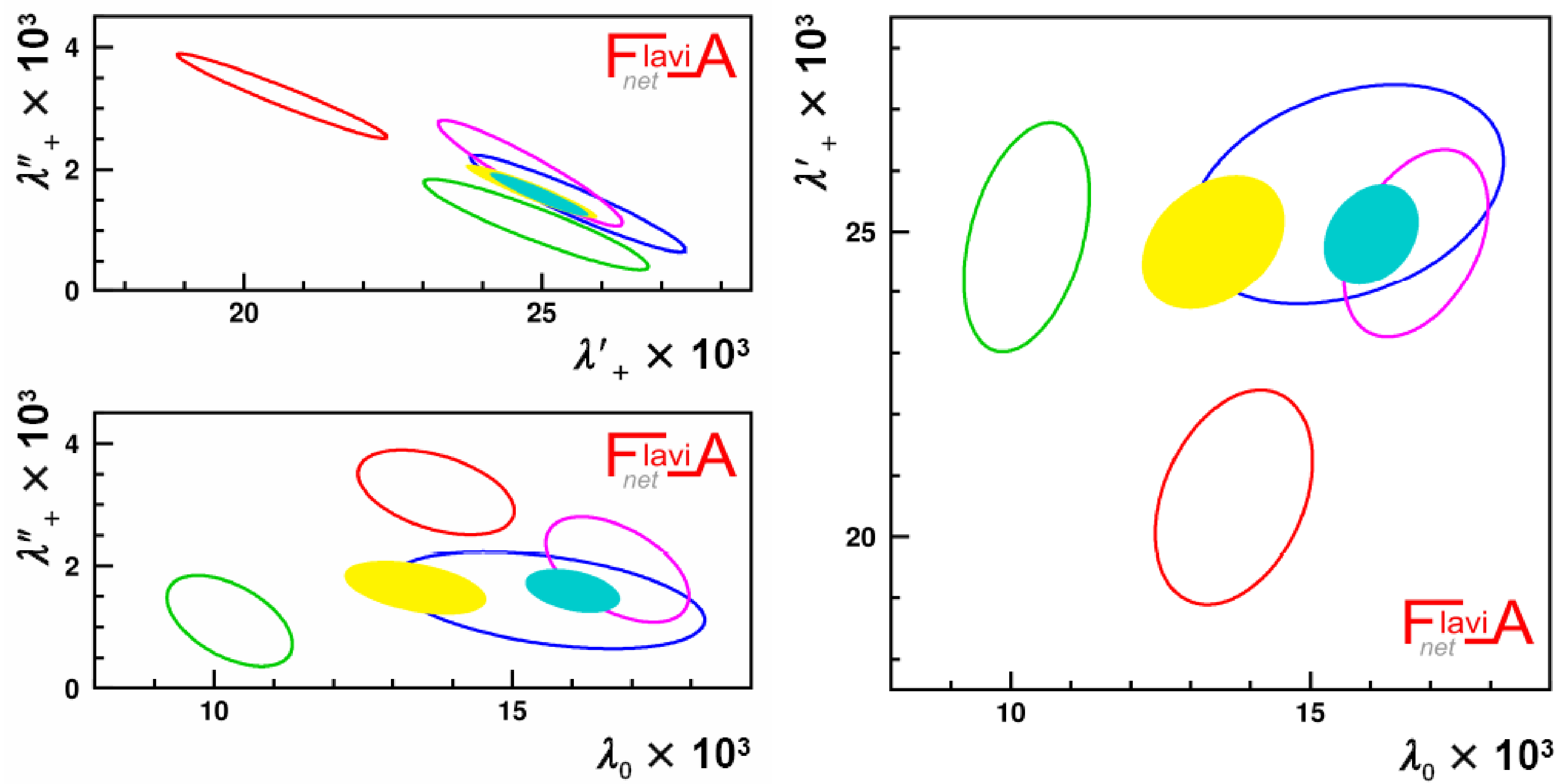
(correlations between λ_0' and λ_0'' = - 99.96%)

KLOE preliminary arXiv:0710.4470

$\lambda'_+ \times 10^3$	$\lambda''_+ \times 10^3$	$\lambda_0 \times 10^3$
25.6 ± 1.8	1.5 ± 0.8	15.4 ± 2.1

K_{l3} slopes comparison

e3 – μ3 averages from **KTeV** **KLOE** **ISTRA+** **NA48**



Kl3 fit, no NA48 *Kμ3*: χ^2=12.6/10 (24.9%) | *Kl3* fit, all data, χ^2=54/13 (10^{-6})

$K_{\mu 3}$ – beyond quadratic parametrization (I)

because of the strong correlation between λ_0' and λ_0'' , use of the linear rather than the quadratic parametrization gives $\lambda_0 \sim \lambda_0' + 3.5\,\lambda_0''$
to clarify this ➔ is necessary a ff parametrization with t and t^2 terms but one parameter

the Callan-Treiman relation fixes the value of $f_0(t) = \tilde{f}_0(t) f_+(0)$ at $t=\Delta_{K\pi}= m_K^2-m_\pi^2$

$$\tilde{f}_0(\Delta_{K\pi}) = \frac{f_K}{f_\pi}\frac{1}{f_+(0)} + \Delta_{CT}$$

where $\Delta_{CT} = -3.5 \times 10^{-3}$

recent parametrization from Stern & coll. *(PLB638 -2006)* allows such constraint to be exploited ➔ a dispersion relation for $\ln f_0(t)$ is subtracted at t=0 and $t=\Delta_{K\pi}$, giving

$$\tilde{f}_0(t) = \exp\left[\frac{t}{m_K^2 - m_\pi^2}\left(\ln C - G(t)\right)\right]$$

such that $\tilde{f}_0(\Delta_{K\pi}) = C$, G(t) is derived from $K\pi$ scattering data
as suggested by Stern & coll. a good approximation is given by

$$\tilde{f}_0(t) = 1+\lambda_0\frac{t}{m^2} + \frac{\lambda_0^2 + 0.000416}{2}\left(\frac{t}{m^2}\right)^2 + \frac{\lambda_0^3 + 3\times 0.000416\lambda_0 + 0.0000272}{6}\left(\frac{t}{m^2}\right)^3$$

similar parametrization is obtained for $\tilde{f}_+(t)$

$K_{\mu 3}$ - beyond quadratic parametrization (II)

from $K\mu3$ and $Ke3$ data, we find

$\lambda_+ = (25.7 \pm 0.6) \times 10^{-3}$

$\lambda_0 = (14.0 \pm 2.1) \times 10^{-3}$

$\rho(\lambda_+,\lambda_0) = -0.26$

$\chi^2/ndof = 2.6/3$

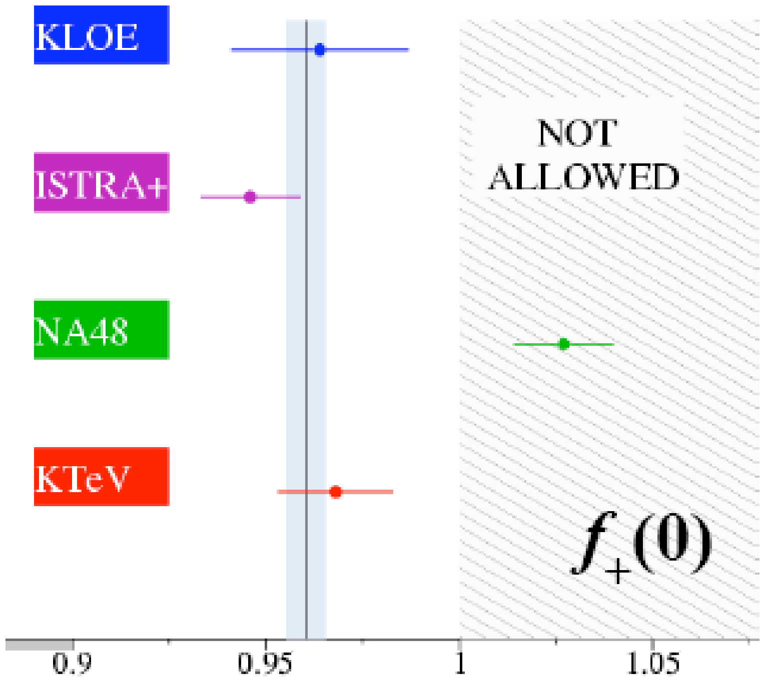
KLOE preliminary arXiv:0710.4470

we evaluate $\tilde{f}_0(\Delta_{K\pi})$ fitting the $K\mu3$ data with the dispersive relation

$$f_0(t) = \exp\left[\frac{t}{m_K^2 - m_\pi^2}(\ln C - G(t))\right]$$

giving $\tilde{f}_0(\Delta_{K\pi}) = C$ = 1.23(3)

$f_+(0) = 0.961(5)$ RBC/UKQCD 07



$f_K/f_\pi = 1.189(7)$ HP-UKQCD 07

KLOE value $f_+(0) = 0.964(23)$ in good agreement with lattice calculations

Tagging of K^+K^- beams

$K^\pm$ beam tagged from

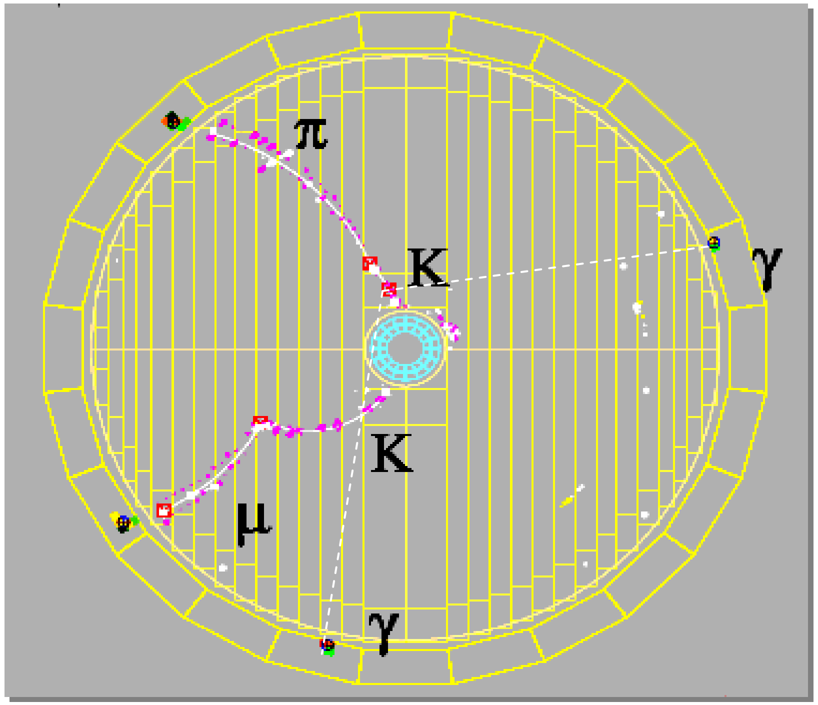
$K^\pm \rightarrow \pi^\pm\pi^0,\ \mu^\pm\nu$ (85% of $K^\pm$ decays)

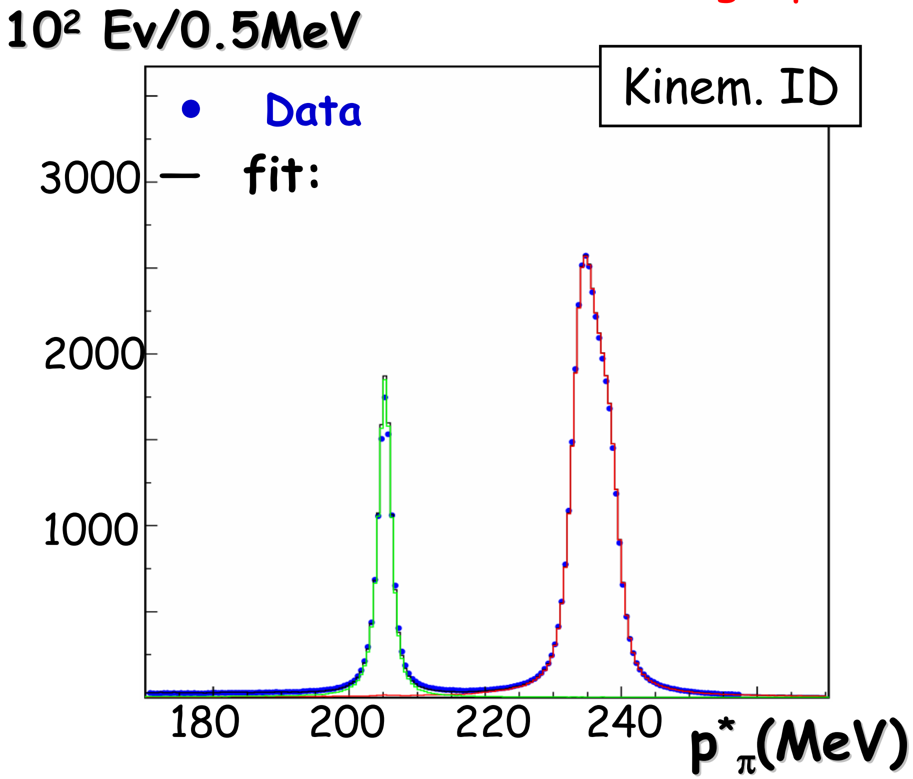
$\cong 1.5 \times 10^6\ K^+K^-$ evts/pb^{-1}

two-body decays identified as peaks in the momentum spectrum of secondary tracks in the kaon rest frame → $P^*(m_\pi)$

$\varepsilon_{tag} \cong 36\ \% \Rightarrow \cong 3.4 \times 10^5\ \mu\nu$ tags/pb^{-1}

$\cong 1.1 \times 10^5\ \pi\pi^0$ tags/pb^{-1}





Measurement of the BR($K^{\pm}_{l3}$): the method

- 4 independent-tag samples: $K^+\mu 2$, $K^+\pi 2$, $K^-\mu 2$, and $K^-\pi 2$

  keep under control the systematic effects due to the tag selection

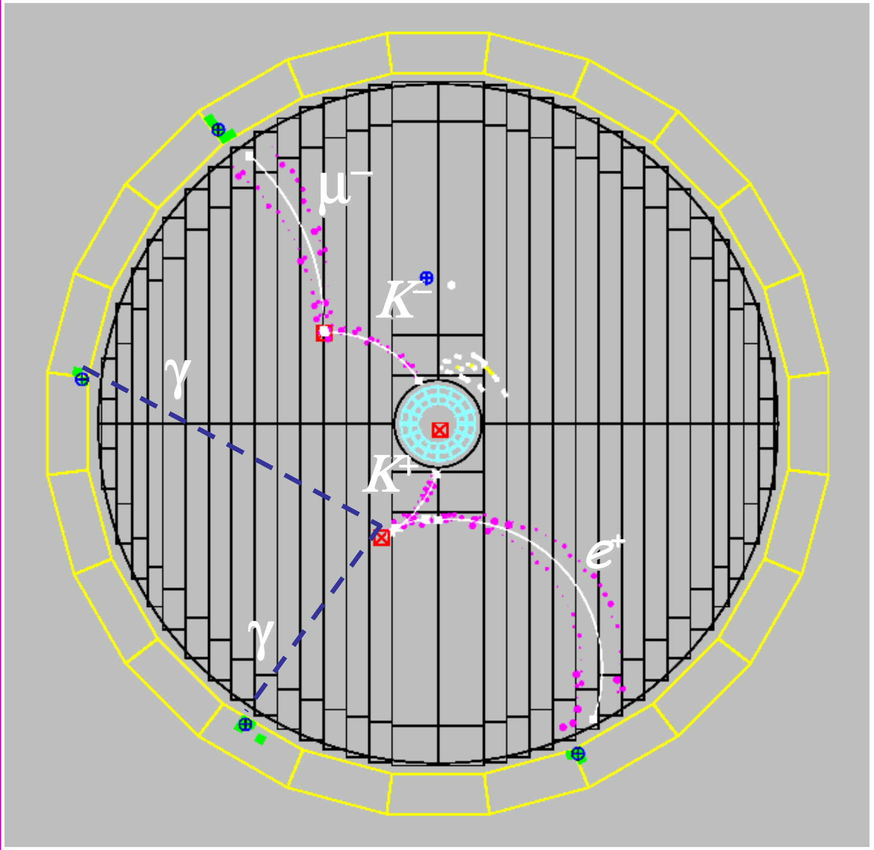
- selection efficiency from MC and correct for Data/MC differences

selection

- 2-tracks vertex in the fiducial volume ($40\ \mathrm{cm} \leq \rho_{xy} \leq 150\ \mathrm{cm}$)
- reject two-body decays by cutting on $P^*(m_\pi) \leq 192$ MeV
- π^0 search $\Rightarrow$ 2 neutral clusters in EmC, with TOF matching the K decay vertex
- obtain charged secondary mass m_l^2 spectrum from TOF measurement

$$t^{decay}_K = t_l - L_l/(\beta_l c) = \langle t_\gamma - L_\gamma/c \rangle$$

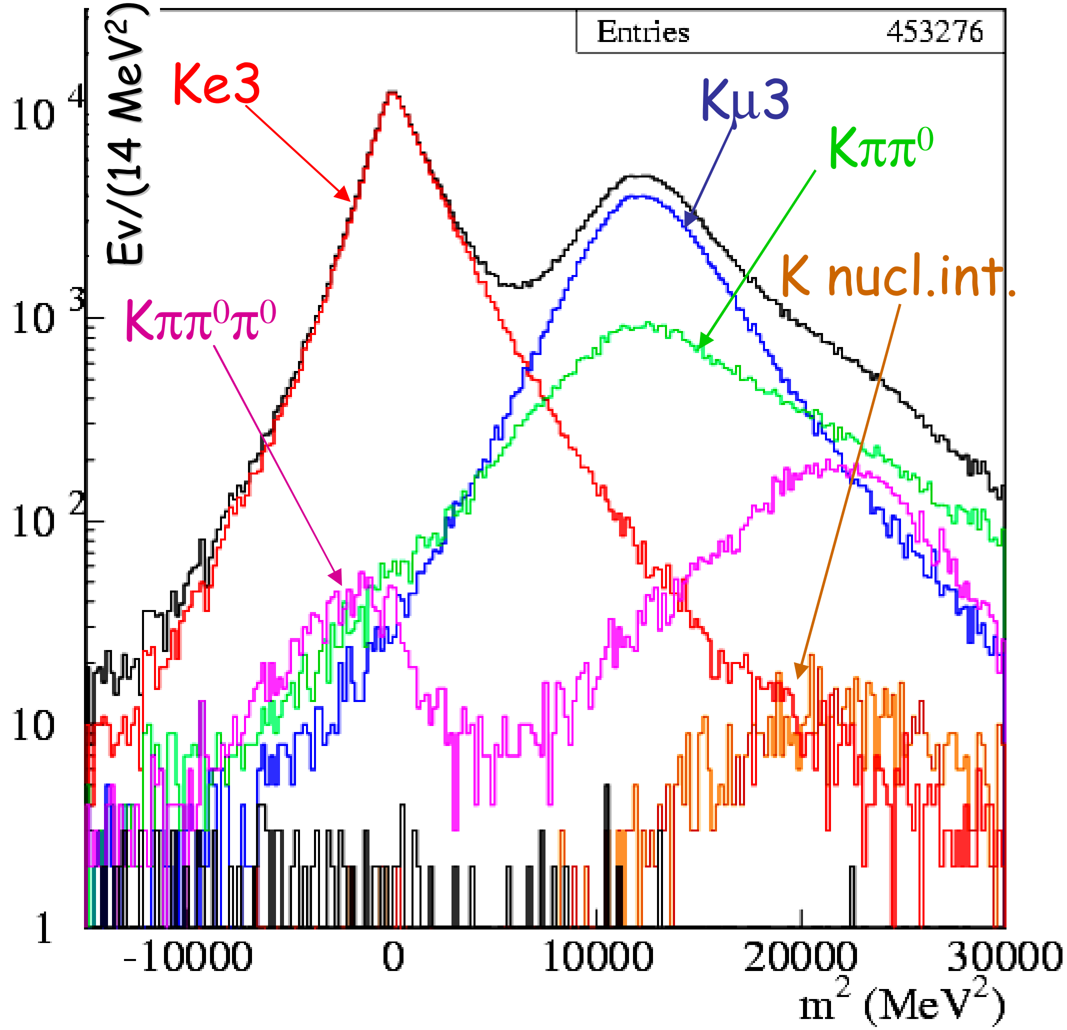
$$m_l^2 = p_l^2 \times [c(t_l - t_\gamma)/L_l)^2 - 1]$$



BR($K^{\pm}_{l3}$): signal and background

- $K \to \pi\pi^0\pi^0$ with a π^0 undergoing a Dalitz decay, give a m_l^2 under the Ke3 peak $\Rightarrow$ reject with a cut on $(E_{miss} - P_{miss}) < 90$ MeV
- $K \to \pi\pi^0$ with an early decay $\pi \to \mu\nu$, give a m_l^2 under the $K\mu3$ peak $\Rightarrow$ rejected evaluating the missing momentum of the secondary track in the pion rest frame ($P^*_{sec} > 90$MeV)

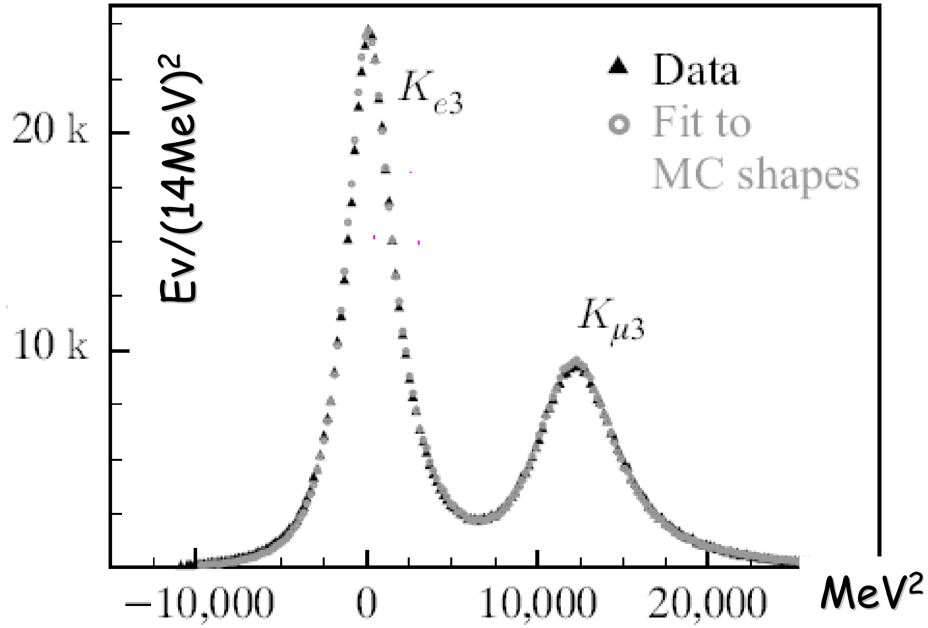
the residual background is $\cong$ 1.5% of the selected $K^{\pm}_{l3}$ sample, and has the m_π^2 signature



Absolute BR's for $K^{\pm}_{l3}$

signal count from a constrained likelihood fit to the m_l^2 spectrum using a linear combination of signal and background shapes from MC

perform the BR measurements on each tag sample, separately normalizing to tag counts in the same data set, and average accounting for correlations



ArXiv:0707.2532

$$BR(K^{\pm}_{e3}) = (4.965 \pm 0.038_{Stat} \pm 0.037_{Syst}) \times 10^{-2}$$
$$BR(K^{\pm}_{\mu 3}) = (3.233 \pm 0.029_{Stat} \pm 0.026_{Syst}) \times 10^{-2}$$
$$R_{\mu e} = 0.6511 \pm 0.046_{Stat} \pm 0.073_{Syst}$$

✓ fractional accuracy of 1.1% for K_{e3} 1.2% for $K_{\mu 3}$
✓ the error is dominated by the error on Data/MC efficiency correction

Measurement of the $K^{\pm}$ lifetime

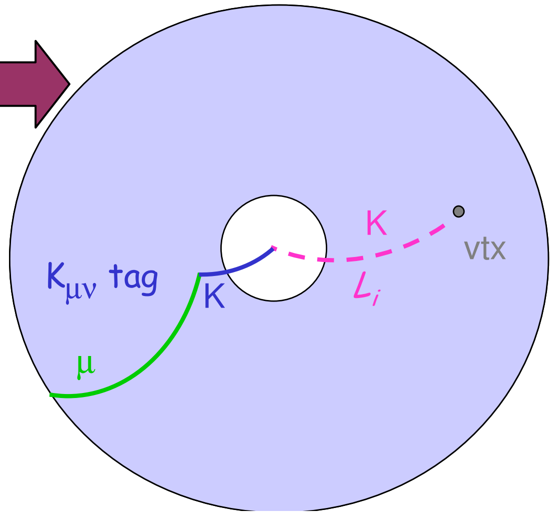
✧ poor consistency of PDG average with measurements spread

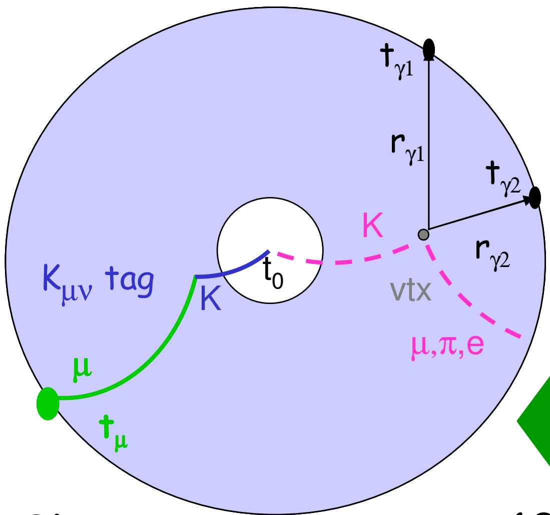
$\delta\tau/\tau \sim 0.2\% \rightarrow \delta V_{us}/V_{us} \sim 0.1\%$ $\delta\tau/\tau \sim 0.8\% \rightarrow \delta V_{us}/V_{us} \sim 0.4\%$

two methods to measure $\tau_{\pm}$ allow cross checks on the systematic error
common to both methods ➔ *tag events with $K_{\mu 2}$ decay, $K^{\pm}$ vtx in the DC*

1st method: $\tau_{\pm}$ from the K decay length

- measure the kaon decay length taking into account the energy loss: $t^* = \sum_i L_i/(\beta_i\gamma_i c)$
- efficiency and resolution functions measured on data by means of π^0 vertex reconstruction ($K \rightarrow \pi^0 X$)





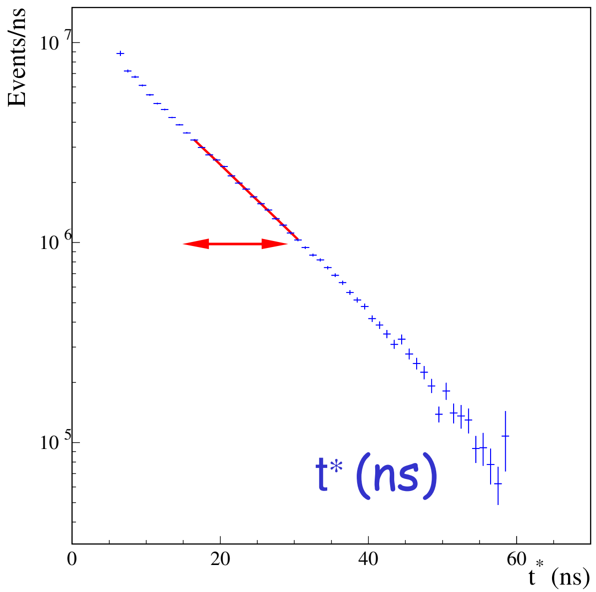
2nd method: $\tau_{\pm}$ from the K decay time

- use $K \rightarrow \pi^0 X$ decays
- use tag information to estimate the T_0
- measure $t^* = (t_\gamma - R_\gamma/c - T_0)\gamma_K$ using the γ clusters
- lorentz factor γ_K: slowly changing along the $K^{\pm}$ path

$K^{\pm}$ lifetime : results

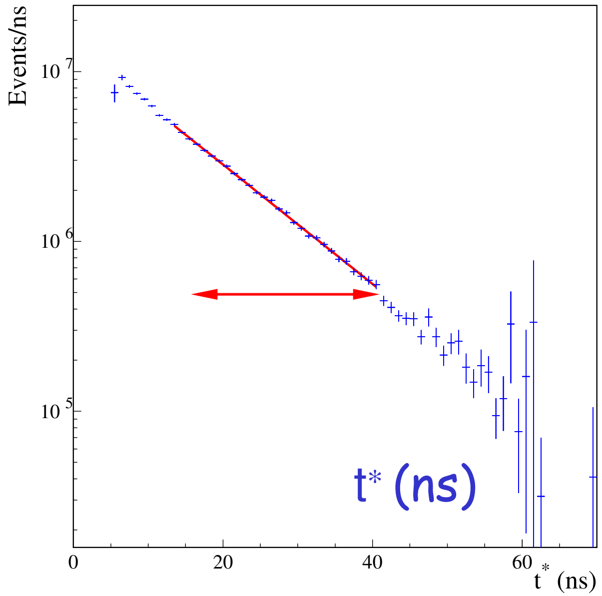
fit to t* distribution from decay length

fit coverage: 16-30 ns (1.1 $\tau^{\pm}$)



fit to t* distribution from decay time

fit coverage: 13-42 ns (2.3 $\tau^{\pm}$)



fit performed folding resolution and efficiency functions

$\tau^{\pm}$ = 12.367(44)(65) ns

$\tau^{\pm}$ = 12.391(49)(25) ns

combined result (ρ = 0.34): $\tau^{\pm}$ = 12.384(48) ns

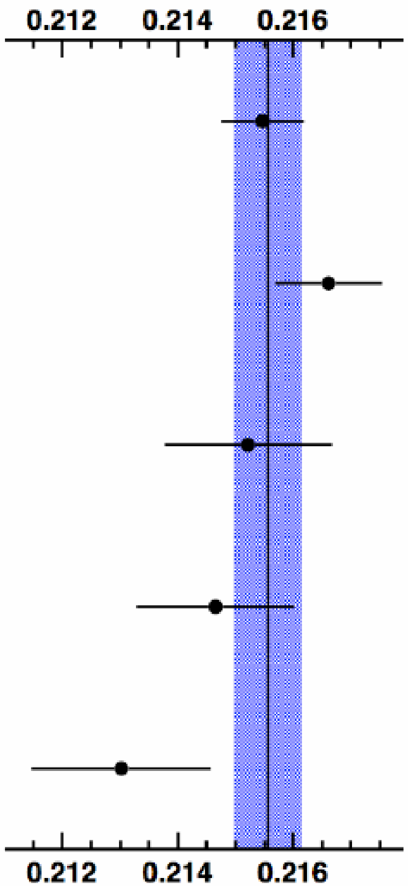
ArXiv:0705.4408

KLOE preliminary

$V_{us}\,f_+(0)$ from KLOE results

BR(K_{l3}) 's, $\tau(K_L)$ and $\tau(K^\pm)$ from KLOE, $\tau(K_S)$ from PDG and ff's from dispersive relations

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



	$|V_{us}|\,f_+(0)$	% err
K_Le3	0.21547(72)	0.34
$K_L\mu3$	0.21661(93)	0.43
K_Se3	0.21522(145)	0.68
$K^\pm e3$	0.21465(137)	0.64
$K^\pm\mu3$	0.21302(155)	0.73

$K^+ - K^0$ diff.: -1.3σ

$\Delta^{SU(2)}{}_{exp}$ = 1.52(63)%

$\Delta^{SU(2)}{}_{theo}$ = 2.36(22)%

$f_+(0)$ = 0.961(5) RBC/UKQCD,07

V_{ud} = 0.97372(26) PRL96 032002,06

$|V_{us}|$ = 0.22433(134)

Unitarity test:

$1 - V_{ud}^2 - V_{us}^2 = 154(79)\times10^{-5}$

Average: $|V_{us}|\,f_+(0)$ = 0.21556(59) χ^2/ndf = 6.1/4 (19%)

V_{us}/V_{ud} from BR ($K^+ \to \mu^+ \nu(\gamma)$)

(Marciano PRL93 231803,2004)

$$\frac{\Gamma(K^\pm \to \mu^\pm \nu(\gamma))}{\Gamma(\pi^\pm \to \mu^\pm \nu(\gamma))} = \frac{|V_{us}|^2 f_K^2 m_K (1 - m_\mu^2/m_K^2)^2}{|V_{ud}|^2 f_\pi^2 m_\pi (1 - m_\mu^2/m_\pi^2)^2} \times 1 \times \alpha(C_K - C_\pi)$$

inputs from theory

$f_K/f_\pi = 1.189(7)$ HP/UKQCD, 07 arXiv:0706.1726

C_K, C_π radiative inclusive electroweak corrections

$1 \times \alpha(C_K - C_\pi) = 0.9930(35)$

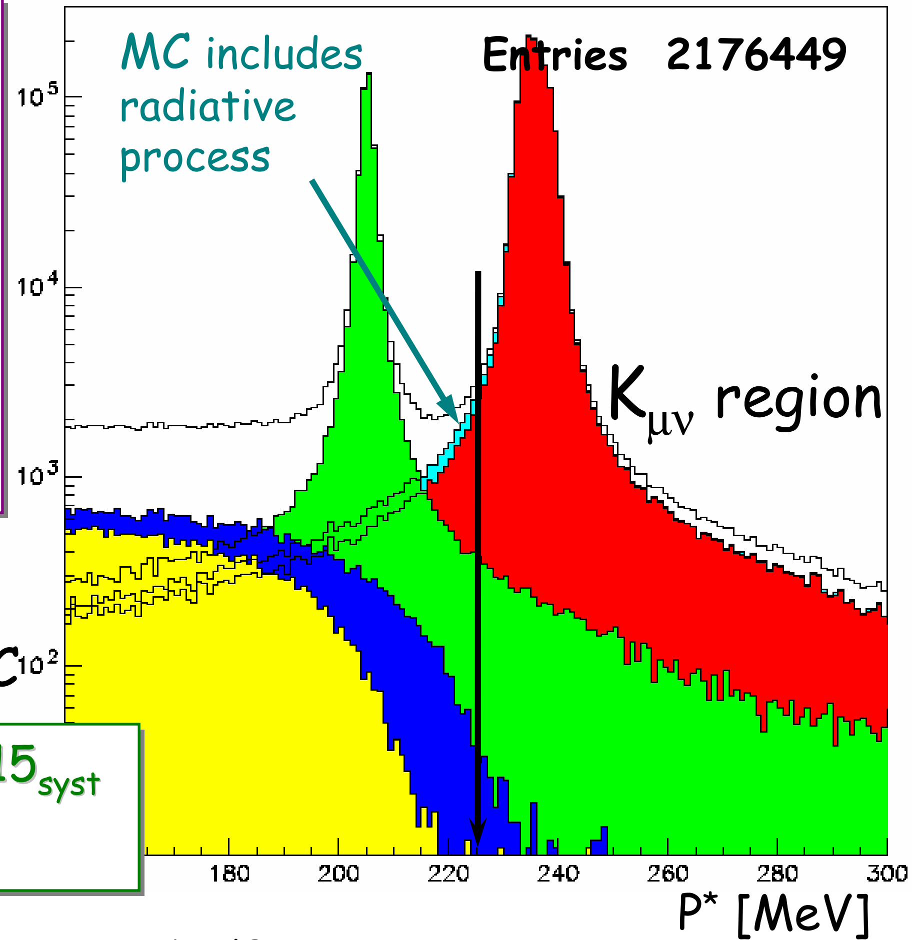
inputs from experiment

$\Gamma(K_{\mu 2(\gamma)})$, $\Gamma(K_{\pi 2(\gamma)})$ rates with well determined treatment of radiative decays

Measurement of the BR ($K^+ \to \mu^+ \nu(\gamma)$)

Signal selection

- tag from $K^- \to \mu^- \nu$
- 175 pb^{-1}: 1/3 used for signal selection, 2/3 used as efficiency sample
- decay vertex in DC & fill the P* spectrum
- subtraction of π^0 identified background
- count events in (225,400) MeV window of the momentum distribution in K rest frame (π hypothesis)



- selection efficiency measured on data
- radiated γ acceptance computed by MC

$BR(K^+ \to \mu^+ \nu(\gamma)) = 0.6366 \pm 0.0009_{stat} \pm 0.0015_{syst}$

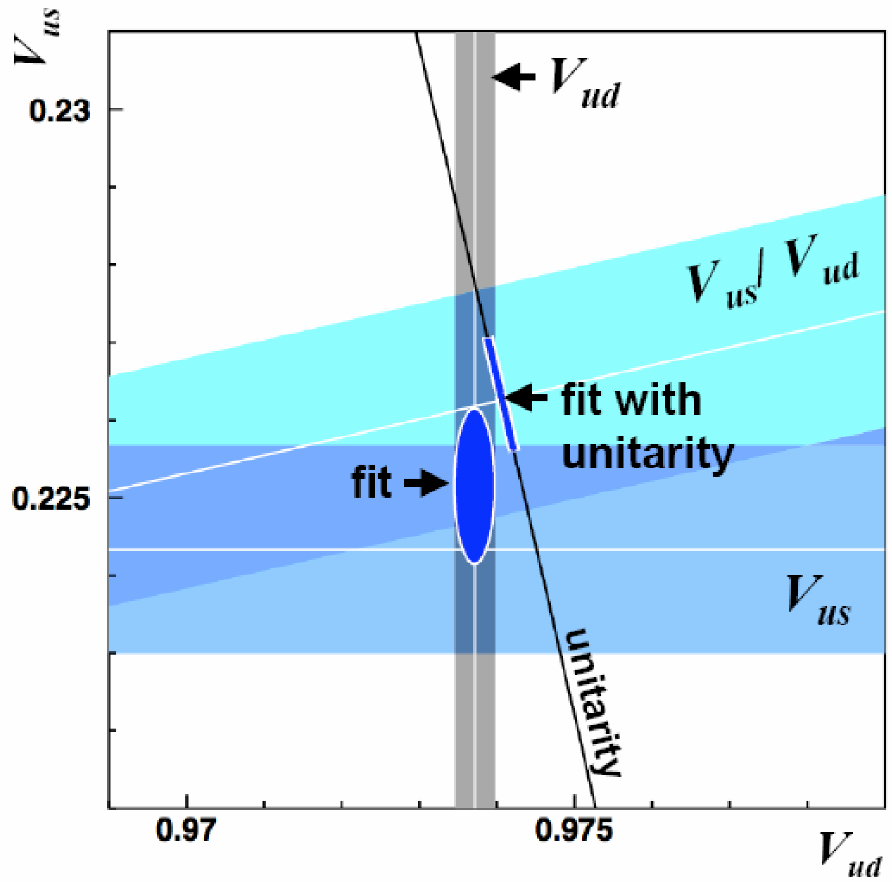
[PLB 632 (2006)]

f_K/f_π = 1.189(7) from UKQCD '07

$|V_{us}|/|V_{ud}| = 0.2321 \pm 0.0013$

V_{us} - V_{ud} plane

V_{ud} = 0.97372(26) from PRL96 032002,06
$f_+(0)$ = 0.961(5) from UKQCD/RBC '07
|Vus| = 0.2243(13) from KLOE K_{l3}



Fit results, no constraint:

V_{ud} = 0.97371(26)
V_{us} = 0.2252(10)
χ^2/ndf = 0.85/1 (36%)

Fit results, unitarity constraint:

V_{ud} = 0.97405(17)
V_{us} = 0.2263(7)
χ^2/ndf = 3.8/2 (14.6%)

Agreement with unitarity 1.5σ

Measurement of the $BR(K^+ \to \pi^+\pi^0)$

✓ needed to perform a global fit to $K^\pm$ BR's
✓ only K_{l3} and $K_{l3}/K_{\pi 2}$ measured recently
✓ available measurement dates back to '72 (no radiative corrections)

PDG fit '06 $BR(K^\pm \to \pi^\pm\pi^0) = (20{,}92 \pm 0.12)\%$ $\Delta BR/BR = 5{,}7\text{x}10^{-3}$

CHIANG '72 $BR(K^\pm \to \pi^\pm\pi^0) = (21{,}18 \pm 0.28)\%$ $\Delta BR/BR = 1{,}3\text{x}10^{-3}$

this decay enters in the normalization of $BR(K^\pm l3)$ by NA48, ISTRA+, E865

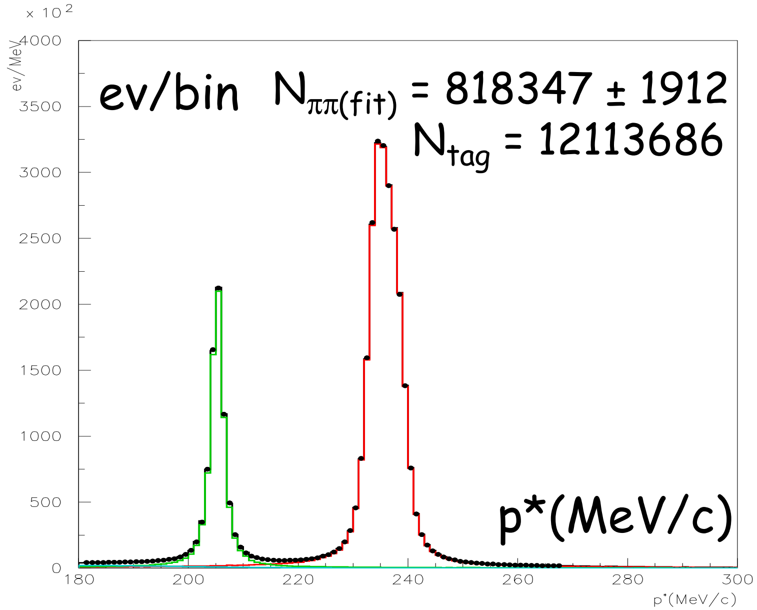
- normalization sample N_{tag} given by $K^- \to \mu^-\bar{\nu}$ tag

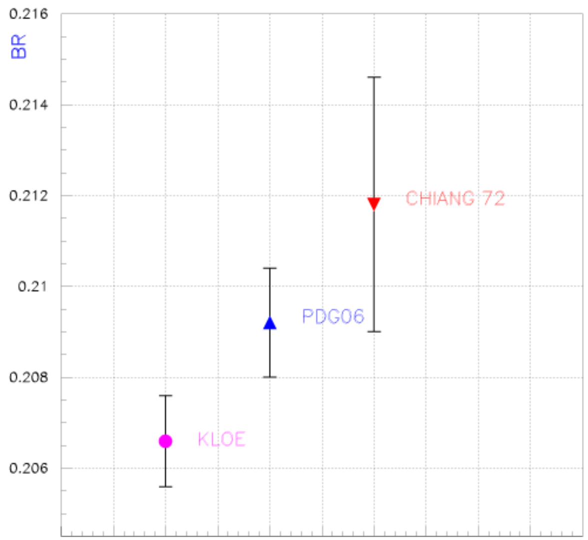
- fit the distribution of the momentum of the charged decay particle in the kaon rest frame assuming the pion mass (p*)

the selection efficiency is only related to DC reconstruction
$\Rightarrow$ global efficiency $\varepsilon_{TRK+VTX}$
measured on data by means of π^0 vertex reconstruction ($K \to \pi^0 X$)

Measurement of the BR($K^+ \to \pi^+\pi^0$)

- signal count from the fit the p* distribution with three contributions
  - $\mu\nu$ peak from DATA control sample selected using calorimetric information only
  - $\pi\pi^0$ peak from DATA control sample selected using calorimetric information only
  - 3-body decays from MC
- normalize to the number of tags
- correct for the selection efficiency





KLOE preliminary

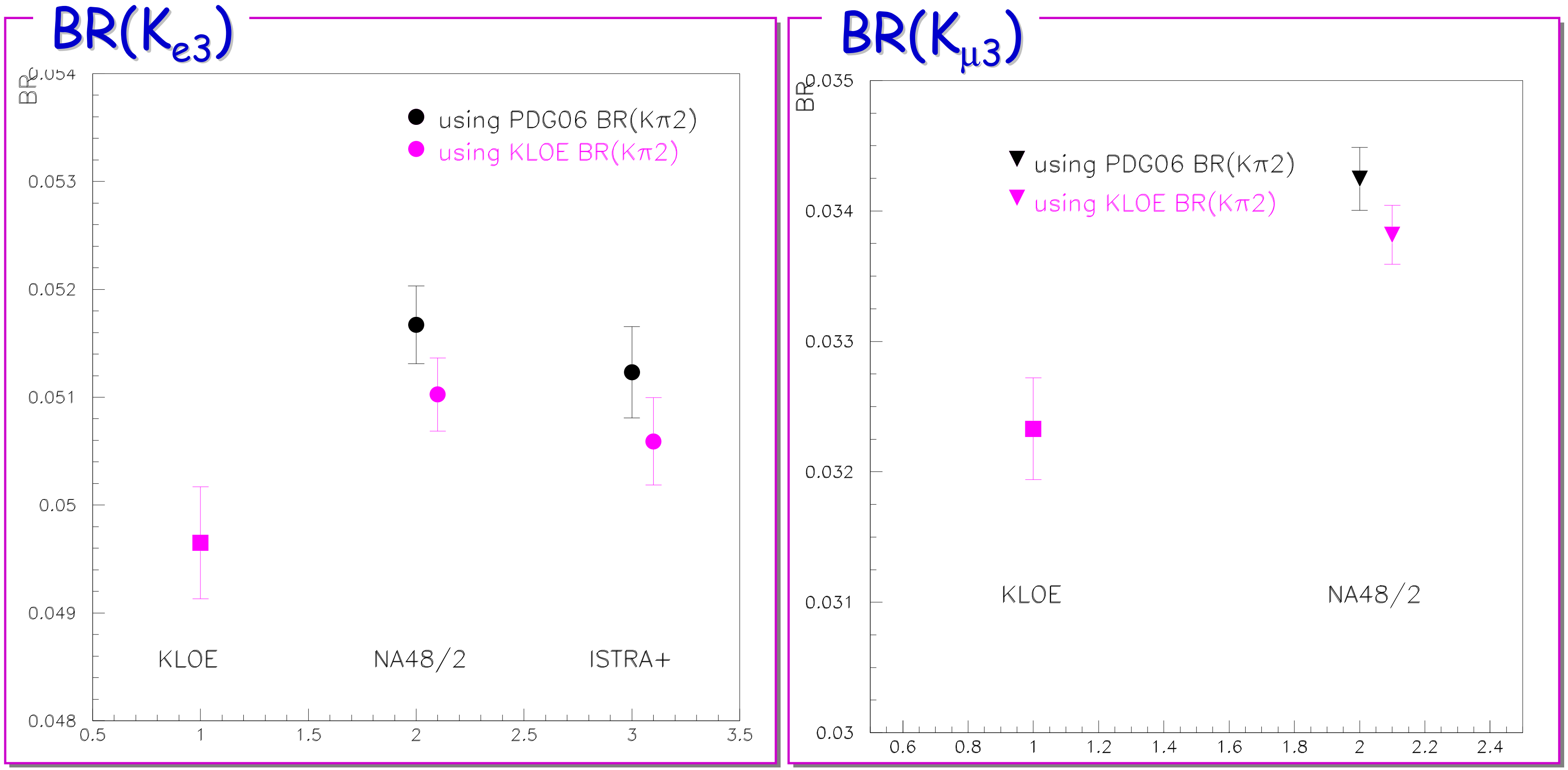
$BR(K^+ \to \pi^+\pi^0(\gamma)) = (20.658 \pm 0.065_{stat} \pm 0.090_{syst})\%$

-1.3% respect to PDG 06 $\sigma_{rel} \sim 0.5\%$

ArXiv: 0707.4631

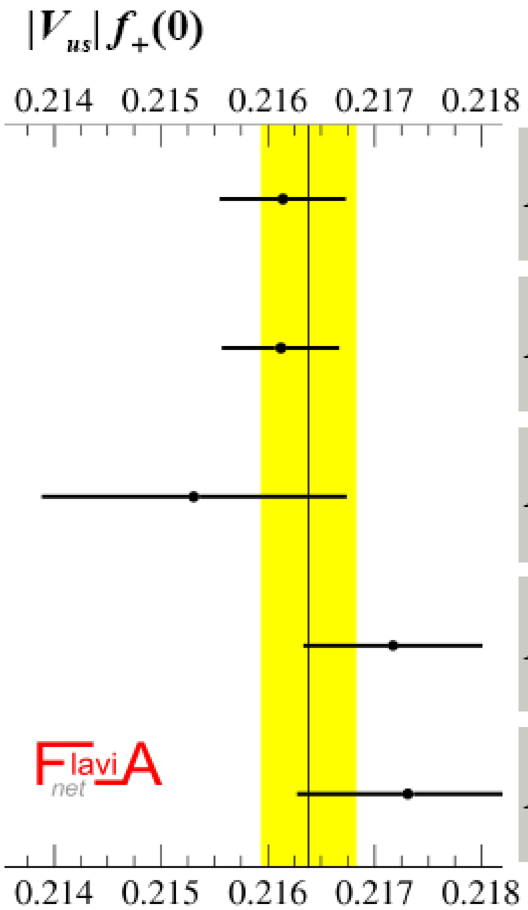
Measurement of the BR($K^+ \rightarrow \pi^+ \pi^0$)

impact of the new measurement wrt PDG 06 fit value on the BR($K^{\pm}_{l3}$) measurements normalized to $K_{\pi 2}$ decays and comparison with absolute BR($K^{\pm}_{l3}$) measurements from KLOE



$V_{us}f_+(0)$ from world data

the *FlaviaNet Kaon WG* performs fits to world data on the BRs and lifetime for the K_L, K_S, $K^\pm$ with the constraint that the BRs sum to unity



			Approx. contrib. to % err from:		
		% err	BR	τ	Δ
K_Le3	**0.21614(59)**	**0.27**	0.09	0.19	0.15
$K_L\mu3$	**0.21612(55)**	**0.25**	0.10	0.18	0.15
K_Se3	**0.21531(143)**	**0.67**	0.65	0.03	0.15
$K^\pm e3$	**0.21717(84)**	**0.39**	0.26	0.09	0.26
$K^\pm\mu3$	**0.21731(104)**	**0.48**	0.40	0.09	0.26

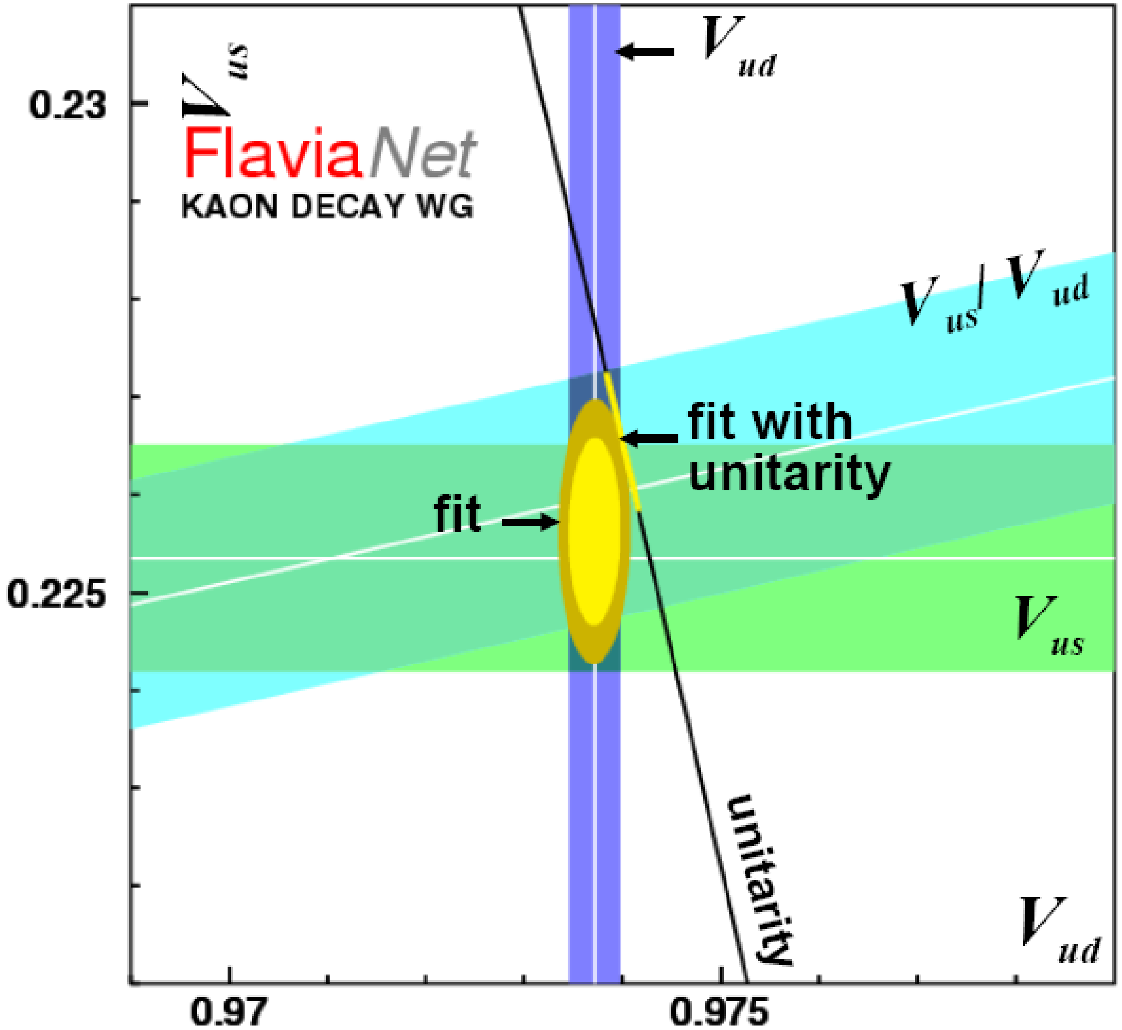
$f_+(0)$ = 0.961(5) from UKQCD/RBC '07

Average: $|V_{us}|$ = 0.22535(116) χ^2/ndf = 1.78/4 (78%)

V_{us} - V_{ud} plane

$f_+(0)$ = 0.961(5) from UKQCD/RBC '07
$|V_{us}|$ = 0.22535(116) from K_{l3}

f_K/f_π = 1.189(7) from UKQCD '07
$|V_{us}/V_{ud}|$ = 0.2321(13) from K_{l2}



fit results, no constraint

V_{ud} = 0.97372(26)
V_{us} = 0.2256(10)
χ^2/ndf = 0.17/1 (68%)

fit results, unitarity constraint

$V_{us} = \sin\theta_c = \lambda$ = 0.2265(7)
χ^2/ndf = 2.24/2 (33%)

agreement with unitarity 1σ

Unitarity test of CKM: G_F universality

comparison between weak couplings from K decays (G_{CKM}) and from τ_μ (G_F)

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

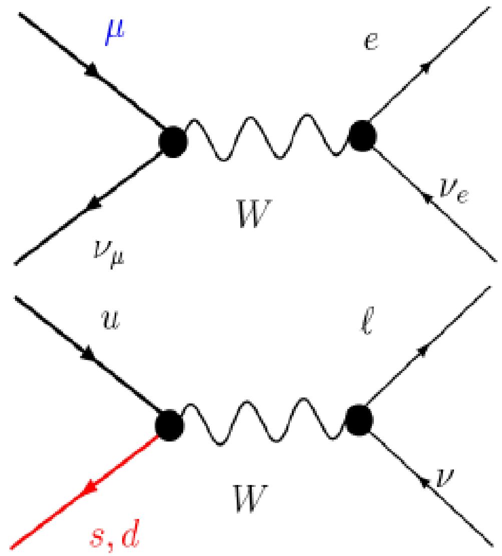
agreement within ~ 1.4σ

G_F = 1.166371(6) x 10^{-5} GeV^{-2}

FlaviA net

G_{CKM} = 1.16581(39) x 10^{-5} GeV^{-2}

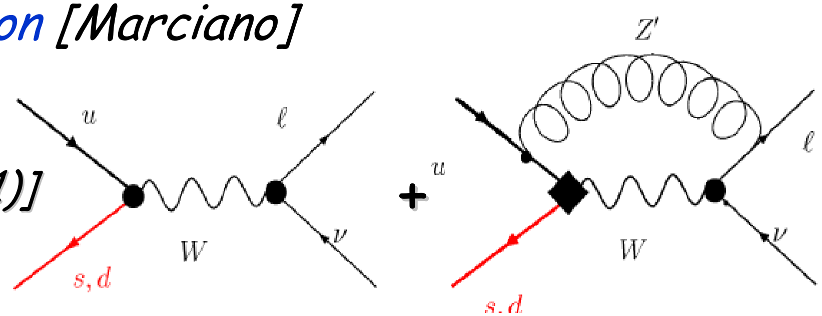
18 ⊕ 20
V_{us} V_{ud}



constraints on NP models, e.g. SO(10) Zχ boson [Marciano]

$G_F = G_{CKM}\,[1-.007 \times 8/3 \times \ln(M_{Z\chi}/M_W)/(M_{Z\chi}^2/M_W^2-1)]$

implies $M_{Z\chi}$ > 1.4 TeV @ 95% CL



$K_{\mu 2}$: sensitivity to charged Higgs

helicity suppressed decays can be sensitive to H^+ exchange, $\Gamma(K \to \mu\nu)$

$$\frac{\Gamma(M \to \ell\nu)}{\Gamma_{SM}(M \to \ell\nu)} = \left[1 - \tan^2\beta \left(\frac{m_{s,d}}{m_u + m_{s,d}}\right) \frac{m_M^2}{m_H^2}\right]^2$$

M = K,π

[Hou, Isidori, Paradisi]

sizable effects in $\Gamma(K \to \mu\nu)$ only

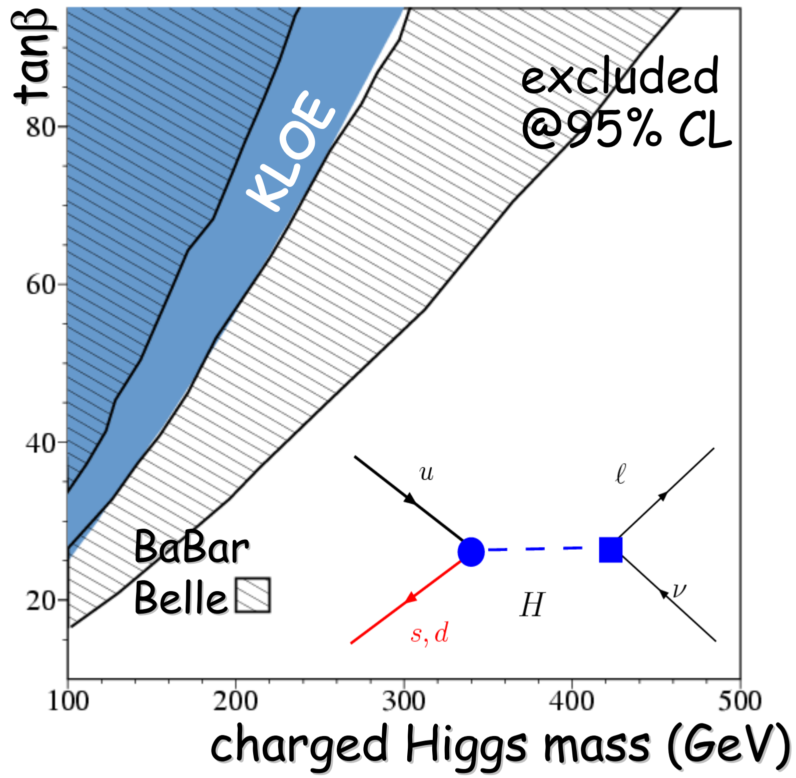
SM prediction, V_{us} from K_{l3} decays, V_{ud} from β-decays and $\pi_{\mu 2}$

FlaviA net $BR(K^+ \to \mu\nu(\gamma)) = 0.6353(77)$

Measurement

KLOE $BR(K^+ \to \mu\nu(\gamma)) = 0.6366(17)$

compare sensitivity with $B \to \tau\nu$ (BaBar Belle average)



LF violation test @ KLOE

Lepton universality from K_{l3}

for K_L and $K^\pm$ we evaluate

$$r_{\mu e} = \frac{(R_{\mu e})_{obs}}{(R_{\mu e})_{SM}} = \frac{\Gamma_{\mu 3}}{\Gamma_{e3}} \cdot \frac{I_{e3}\,(1+\delta_{e3})}{I_{\mu 3}\,(1+\delta_{\mu 3})} = \frac{[|V_{us}|\,f_+(0)]^2_{\mu 3,\,obs}}{[|V_{us}|\,f_+(0)]^2_{e3,\,obs}} = \frac{g_\mu^2}{g_e^2}$$

using only KLOE results we get an accuracy of ~ 0.004

K_L	$g_\mu^2/g_e^2 = 1.0054(44)$	cfr with	$g_\mu^2/g_e^2 = 1.0232(68)$ [PDG04]
K^+	$g_\mu^2/g_e^2 = 0.9924(54)$	cfr with	$g_\mu^2/g_e^2 = 1.0020(80)$ [PDG04]
Avg	$g_\mu^2/g_e^2 = 1.0005(38)$		

compare with

$\tau \to l\nu\nu$ $\quad g_\mu^2/g_e^2 = 1.0005(41)$ [PDG07]

$\pi \to l\nu$ $\quad g_\mu^2/g_e^2 = 1.0034(30)$ [Erler, Ramsey-Musolf '06]

by averaging, we can test equality of weak coupling for e and μ @ 2×10^{-3}

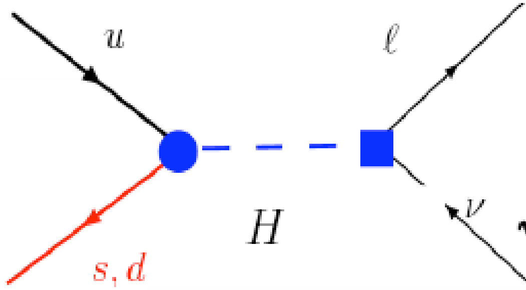
K, π, τ $\quad g_\mu^2/g_e^2 = 1.0019(21)$

Lepton universality from $R_K = K_{e2}/K_{\mu 2}$

- extremely well known within SM $R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$
- in MSSM, LFV could give up to % deviations [Masiero, Paradisi, Petronzio]

NP dominated by contribution of $e\nu_\tau$

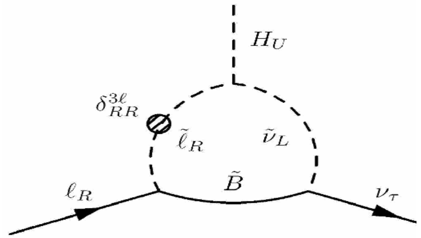
$$R_K \approx \frac{\Gamma(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma(K \to \mu\nu_\mu)}$$



$\nu_e \, \nu_\mu \, \nu_\tau$

with effective coupling

$$eH^{\pm}\nu_\tau \to \frac{g_2}{\sqrt{2}} \frac{m_\tau}{M_W} \Delta_R^{31} \tan^2\beta$$



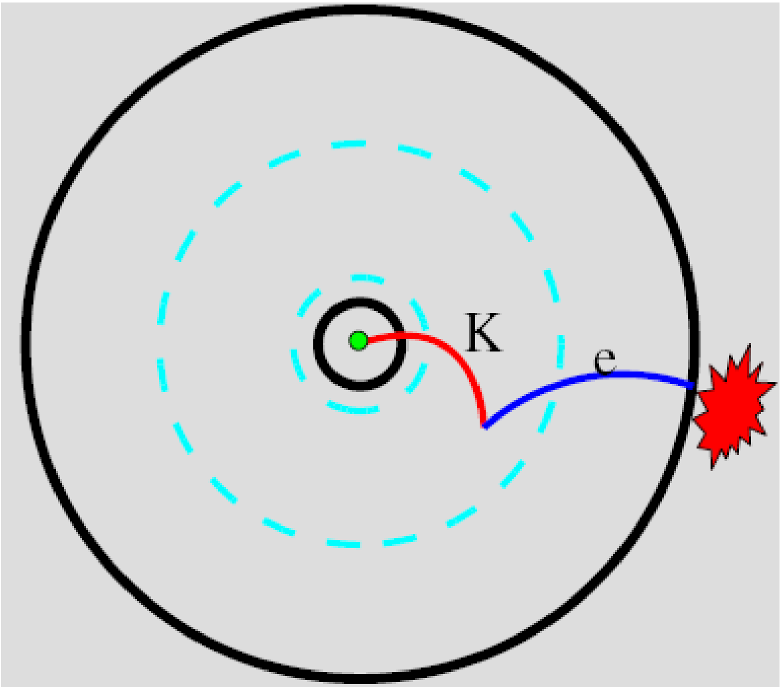
$$\Rightarrow \quad R_K \approx R_K^{SM}\left[1 + \frac{m_K^4}{m_H^4} \frac{m_\tau^2}{m_e^2} |\Delta^R_{31}|^2 \tan^6\beta\right]$$

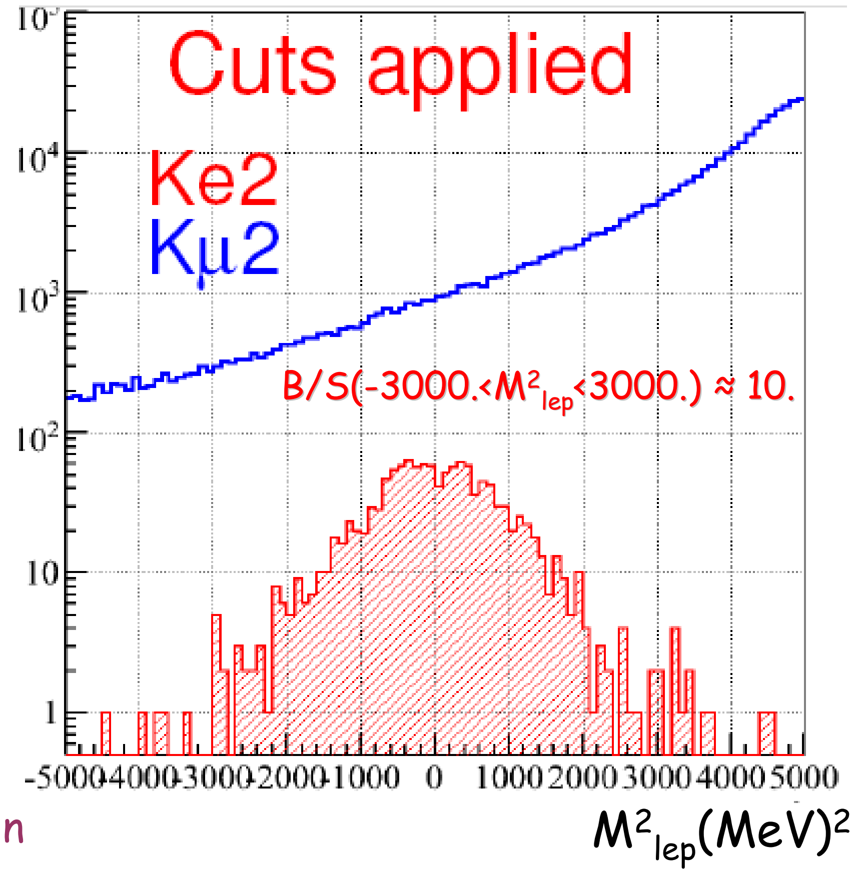
1% effect ($\Delta^R_{31} \sim 5\times10^{-4}$, $\tan\beta \sim 40$, $m_{H+} \sim 500$ GeV) not unnatural
present accuracy on R_K @ 6% (PDG06) ➔ new precise measurements @ < 1%

Searching for K_{e2} @ KLOE (I)

BR(Ke2)≈2×10^{-5}, expect 4×10^{4} events in KLOE data sample (2.3 fb^{-1})

- perfom direct search for Ke2 without tag ➔ gain x 4 of statistic
- search for a vertex inside the Fiducial Volume (40 < ρ_{xy} < 150) cm
- cuts on track quality for $K^{\pm}$ and secondary tracks, cuts on vtx quality

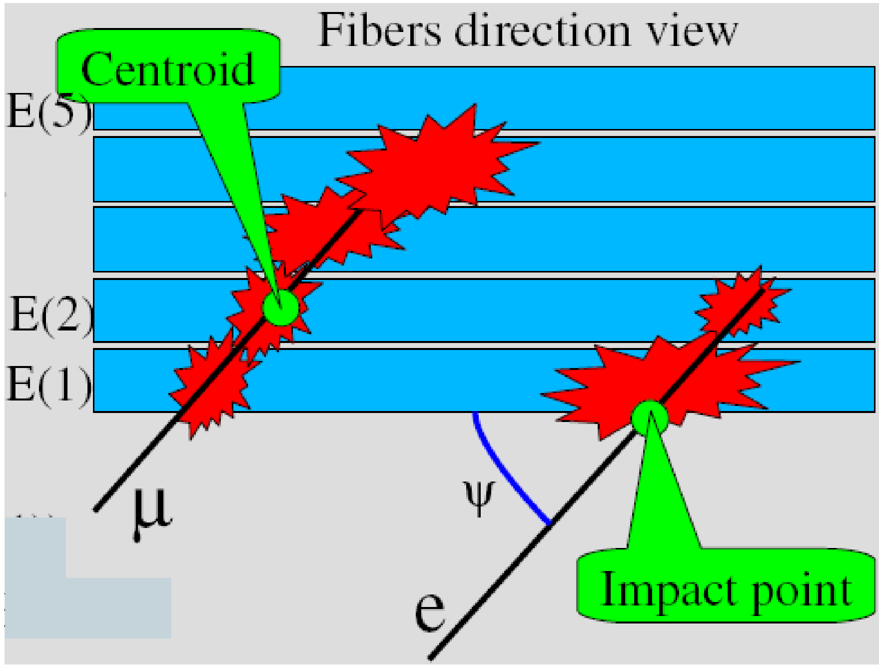


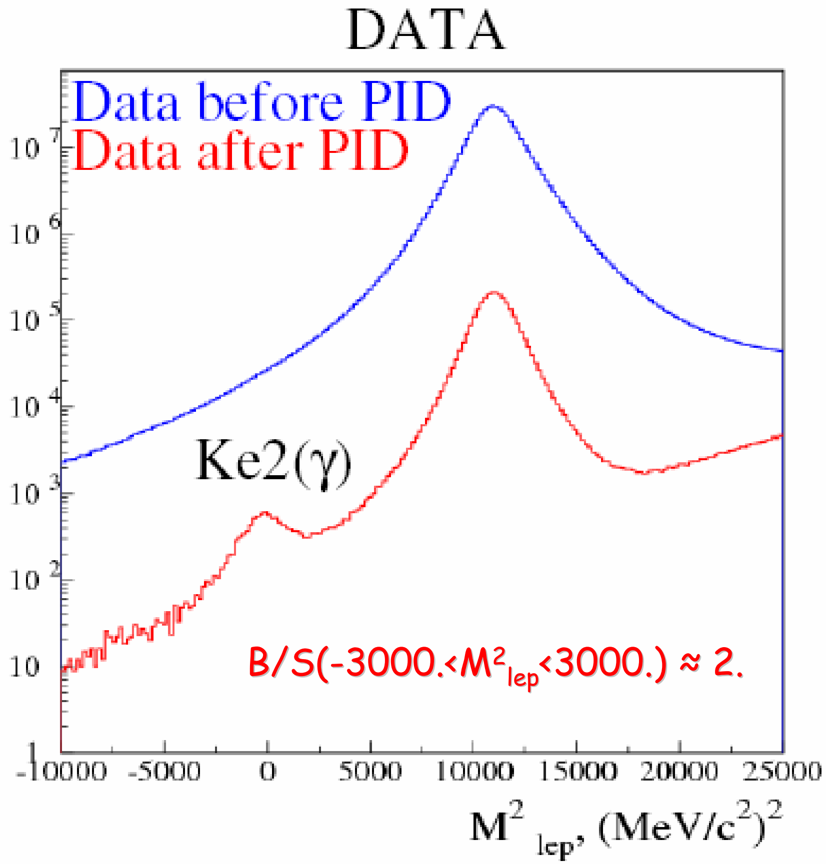


- kaon momentum is measured with 1% resolution
- close kinematics ➔ we get M_{lep}

Searching for K_{e2} @ KLOE (II)

- PID exploits the granularity of KLOE EmC ➔ shower profile along the particle path
- variables used: $E^2_{RMS} = \Sigma_{i=1..N}(E(i)-\langle E\rangle)^2/N$, E/P, cluster shape

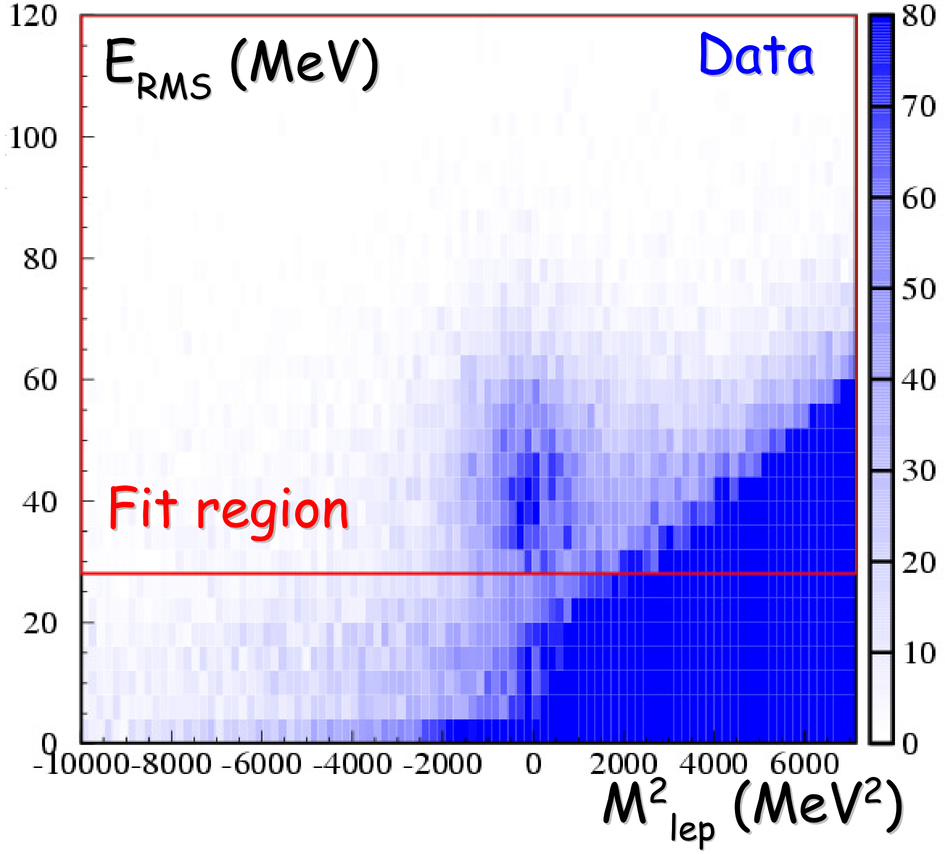


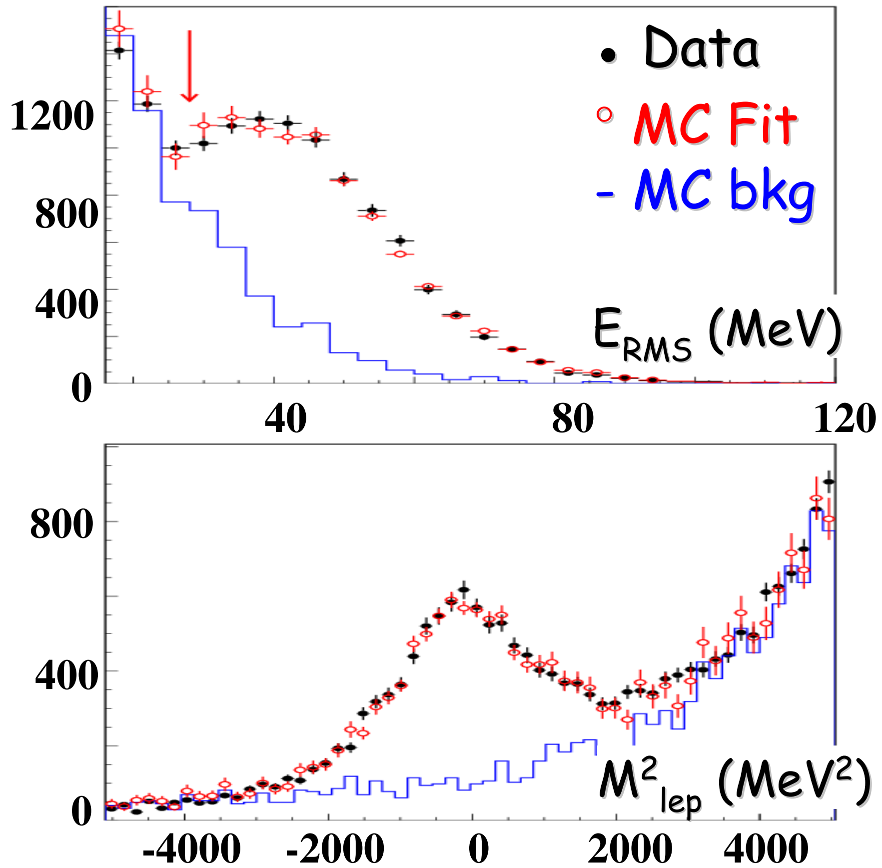


- signal efficiency 0.647(6)
- background rejection ~ 300

K_{e2} signal event counting

- K_{e2} event counts: likelihood fit of M_{lep} vs E_{RMS}
- input: MC shapes for $K_{e2(\gamma)}$ and background
- fit parameters: # of K_{e2} and background, get 8090±160 observed evts



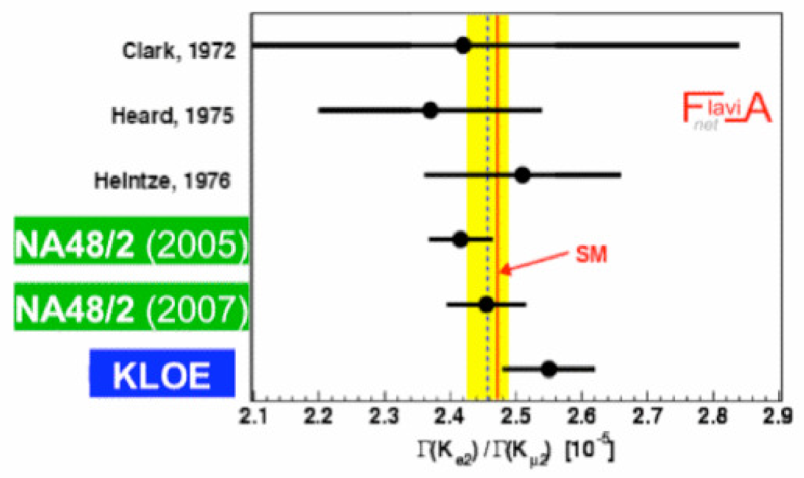


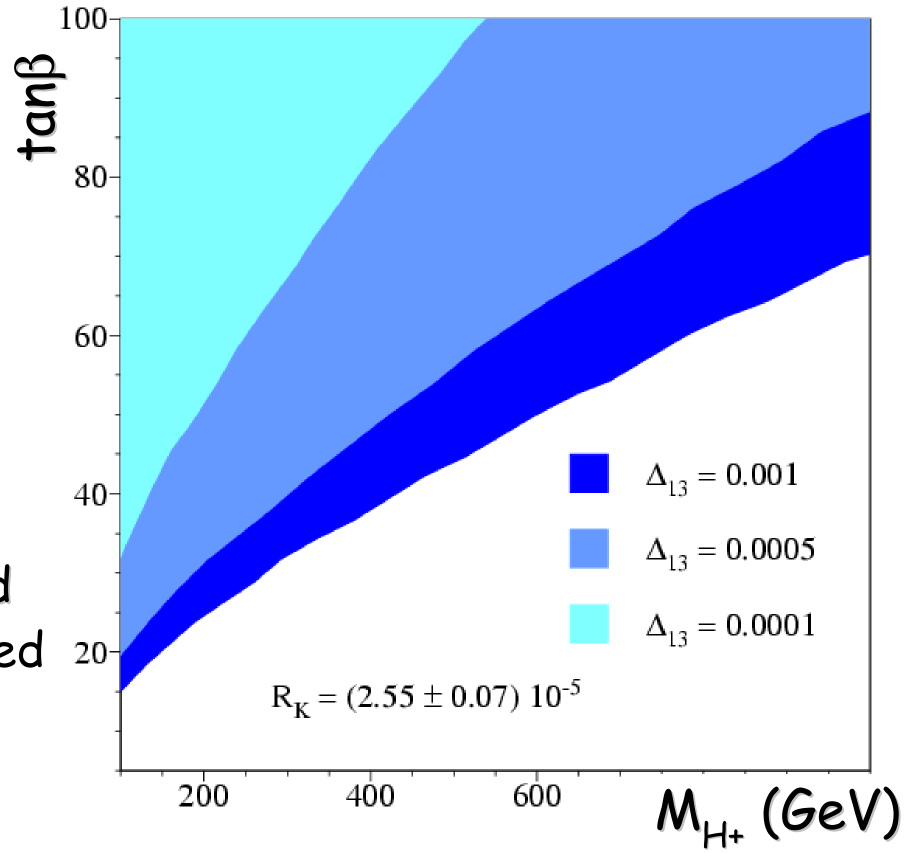
- correct for ratio of K_{e2} and $K_{\mu 2}$ trigger and vtx efficiencies, and for PID K_{e2} efficiency

$R_K = K_{e2}/K_{\mu 2}$ preliminary result

KLOE preliminary result with 2.7% uncertainty

$R_K = 2.55(5)(5) \times 10^{-5}$





sensitivity shown as 95% C.L. excluded regions in the tanβ – M_{H+} plane, for fixed values of the 1-3 slepton-mass matrix element, $\Delta_{13} = 10^{-3}, 0.5\times10^{-3}, 10^{-4}$

Search for rare K_S decays @ KLOE

the K_L crash Tag provides a pure K_S beam

$BR(e^+e^- \rightarrow K_SK_S+K_LK_L)/BR(e^+e^- \rightarrow \phi \rightarrow K_SK_L) \sim 10^{-10}$

contamination due to fake Tags due to other ϕ decays or cosmics at few % level   easily recognized in the β-E plane

the first KLOE analysis on K_S rare decays has been the search for $K_S \rightarrow 3\pi^0$ carried out with 450 pb^{-1}

$BR(K_S \rightarrow 3\pi^0) < 1.2 \times 10^{-7}$ @ 90% C.L.   PLB 619(2005)61

I will discuss two recent KLOE analysis

- *$BR(K_S \rightarrow \gamma\gamma)$*   *final*
- *$BR(K_S \rightarrow e^+e^-)$*   *preliminary*

Analysis of $K_S \to \gamma\gamma$

$BR(K_S \to \gamma\gamma)$ is an important probe of χPT *[Phys.Rev.D 49 (1994) 2346]*

event preselection (1.6 fb^{-1})

- K_S tagged by K_L crash
- 2 and only 2 γ_{prompt} with

  $E\gamma > 7MeV$

  $\cos(\theta_{\gamma\gamma}) > 0.95$

  $(T_\gamma - R/c) < 5\sigma_t$

event selection

- kinematic fit

  $P_{KS}(K_L crash) = P_{KS}(\gamma\gamma)$

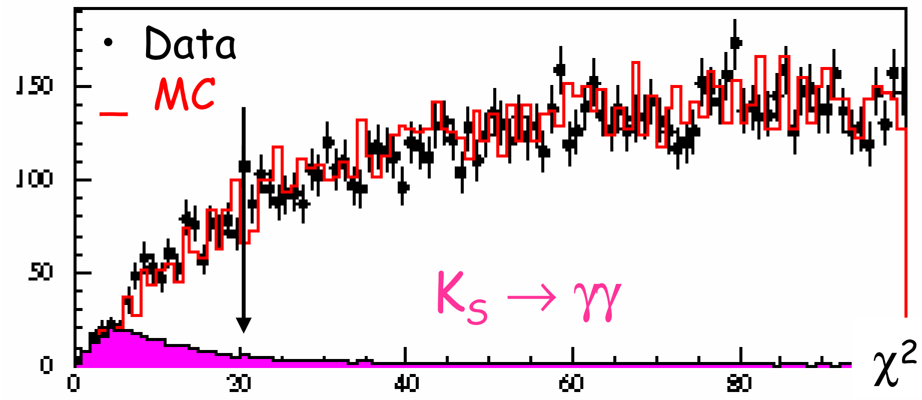
  $M_{\gamma\gamma} = M_{KS}$

  $T_\gamma = R/c$ for both γ's
- QCAL veto

$$BR = N_{\gamma\gamma} \times \frac{\varepsilon_{2\pi 0}}{\varepsilon_{sig}} \times \frac{BR_{2\pi 0}}{N_{2\pi 0}}$$

$\varepsilon_{\gamma\gamma} = \varepsilon_{presel} \times \varepsilon_{sel} \sim 0.83 \times 0.63 \sim 0.50$

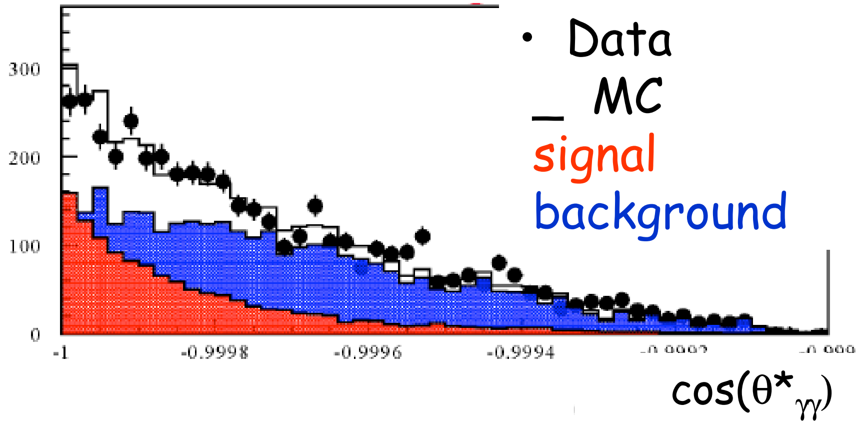
$\varepsilon_{2\pi 0} = 0.65$



✓ *ε(QCAL veto) ~ 1 on signal apart from accidental losses*

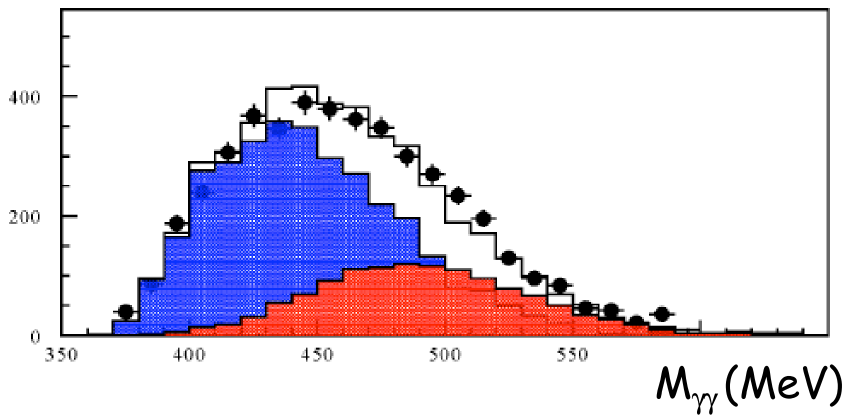
Analysis of $K_S \to \gamma\gamma$

- count signal events fitting the 2D plot of $M_{\gamma\gamma}$ and $\theta^*_{\gamma\gamma}$ in the K_S cms with MC shapes
- $K_L \to \gamma\gamma$ control sample selected to check the energy scale on data-MC



χ^2/Ndof = 1.2

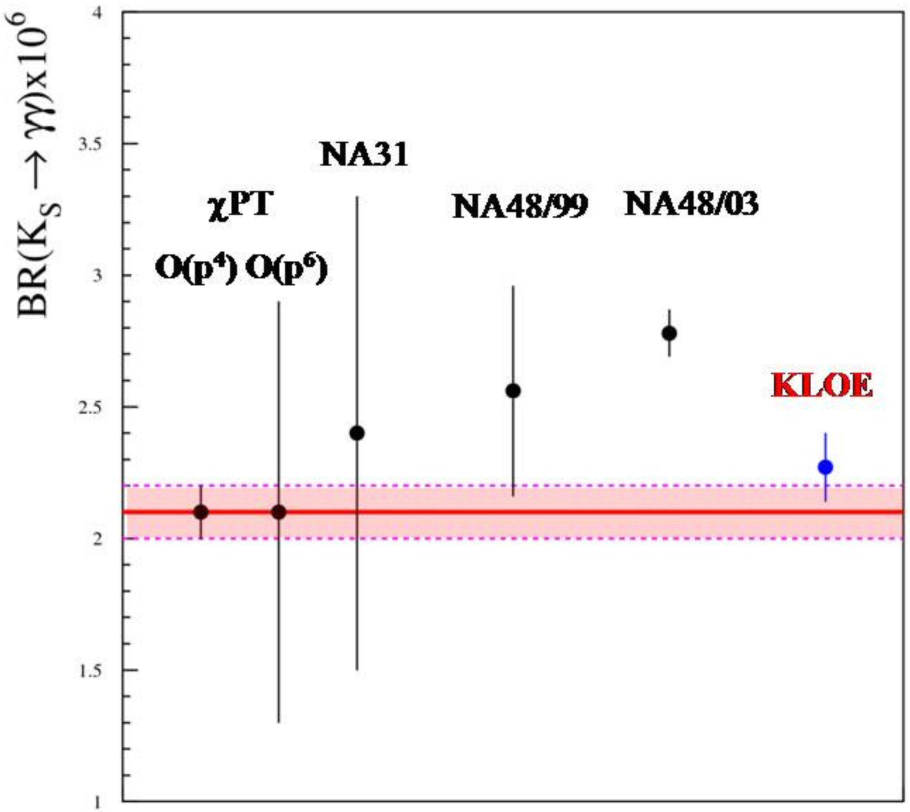
N_{sig} = 600.3 ± 34.8



✓ signal and normalization samples free from $K_L \to \gamma\gamma$ bckg

✓ signal shape cross checked with $K_S \to \pi^+\pi^-$, $K_L \to \gamma\gamma$

$K_S \to \gamma\gamma$: result



KLOE final

$BR = (2.27 \pm 0.13_{stat}{}^{+0.03}{}_{-0.04}) \times 10^{-6}$

arXiv:0707.3933

✓ 2.9 σ from NA48 result
✓ NA48 implied the existence of sizable $\mathcal{O}(p^6)$ counterterm in χPT
✓ our result makes this contribution negligible

Analysis of $K_S \to e^+e^-$

SM prediction is low but precise $BR(K_S \to e^+e^-) = 1.6\times10^{-15}$ *[Ecker, Pich 91]*
leaving room for possible new physics effects to be detected

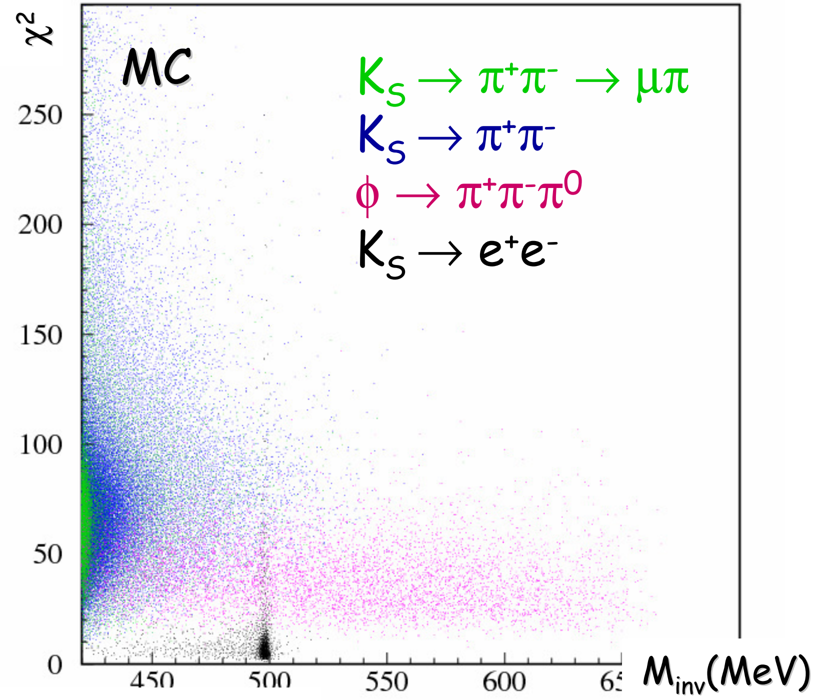
event preselection (1.32 fb^{-1})

- K_S tagged by K_L crash
- 2 tracks from IP to EmC

to identify the signal we build a χ^2-like variable based on

- sum and difference of (T_{clu}-ToF) of the 2 particles
- E/p of both particles
- transverse distance between track impact point and the closest cluster, for both particles

M_{inv} is evaluated in e^+e^- hypothesis



further cuts on

- P* (π hypo) in the K_S rest frame > 220 MeV
- M_{miss} to reject residual $\pi^+\pi^-\pi^0$ > 380 MeV

Analysis of $K_S \to e^+e^-$

$UL(\mu_{sig})$ evaluated numerically with Bayesian approach, taking into account background fluctuations *[NIM 212 (1983) 319-322]*

- optimization of signal box on MC: $(492 < M_{inv} < 504)$ MeV and $\chi^2 < 20$
- we find $N_{obs} = 3$ and $\mu_{BKG} = 7.1 \pm 3.6$ from these $UL(\mu_{sig}) = 4.3$ @90% CL
- without background subtraction $UL(\mu_{sig}) = 6.68$ @ 90% CL

✓ *normalize signal counts to $K_S \to \pi\pi(\gamma)$ counts in the same data set*

$$UL(BR) = UL(\mu_{sig}) \times \frac{\varepsilon_{\pi\pi}}{\varepsilon_{sig}} \times \frac{BR_{\pi\pi}}{N_{\pi\pi}}$$

$$\varepsilon_{sig} = \varepsilon_{presel} \times \varepsilon_{signal\ box} \times \alpha_{\gamma\text{-rad}} = 0.785 \times 0.888 \times 0.8 = 0.558$$

$$\varepsilon_{\pi\pi} = 0.6\ ,\ N_{\pi\pi} = 148174688$$

✓ $\alpha_{\gamma\text{-rad}}$ *acceptance of the radiated photon $E^*_\gamma < 6$MeV*

CPLEAR: 1.4×10^{-7}

KLOE preliminary

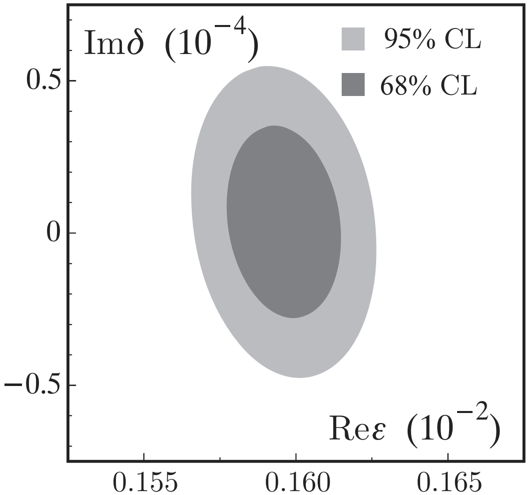
$UL(\ BR(K_S \to e^+e^-(\gamma))\ ) = 2.1 \times 10^{-8}$ @ 90% CL

CPT test: the Bell-Steinberger relation

measurements of K_S K_L observables used for the CPT test from unitarity

$$(1 + i \tan \phi_{SW})\,[\mathrm{Re}\,\varepsilon - i\,\mathrm{Im}\,\delta] = \frac{1}{\Gamma_S}\sum_f A^*(K_S \to f)\,A(K_L \to f) = \sum_f \alpha_f$$

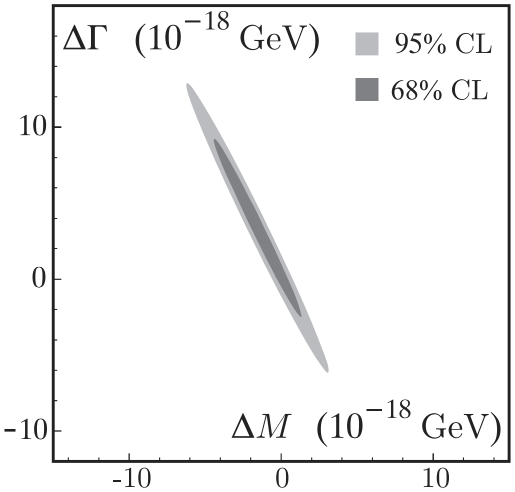
CPLEAR
$\mathrm{Re}\,\varepsilon = (164.9 \pm 2.5)\times 10^{-5}$.
$\mathrm{Im}\,\delta = (2.4 \pm 5.0)\times 10^{-5}$



JHEP12(2006) 011

$\mathrm{Re}\,\varepsilon = (159.6 \pm 1.3) \times 10^{-5}$.
$\mathrm{Im}\,\delta = (0.4 \pm 2.1) \times 10^{-5}$

with $BR(K_S \to 3\pi^0) < 1.2\times 10^{-7}$ @ 90% C.L. [KLOE, PLB 619 (2005)] the main contribution to the uncertainty now comes from η_{+-}



$$\Delta\Gamma = \Gamma(K^0) - \Gamma(\overline{K}^0)$$
$$\Delta M = M(K^0) - M(\overline{K}^0)$$

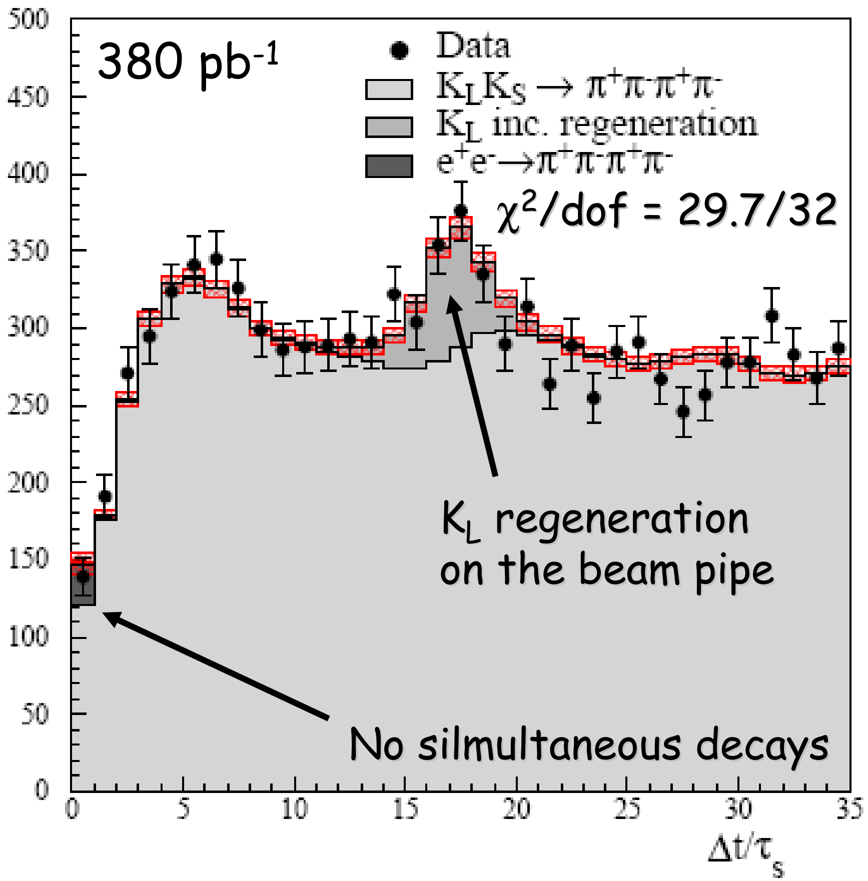
$$\delta = \frac{1}{2}\,\frac{\Delta M - \frac{i}{2}\Delta\Gamma}{(M_L - M_S) + \frac{i}{2}(\Gamma_S - \Gamma_L)}$$

Assuming $\Delta\Gamma = 0$, i.e. no CPT viol. in decay:
$(-5.3 \times 10^{-19} < \Delta M < 6.3 \times 10^{-19})$ GeV at 95% C.L.

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

PLB 642(2006) 315

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



decoherence parameter

$\zeta_{SL} = 0 \quad \to \quad$ QM

$\zeta_{SL} = 1 \quad \to \quad$ total decoherence

- fit including Δt resolution and efficiency effects + regeneration
- Γ_S, Γ_L Δm fixed from PDG

$\zeta_{SL} = 0.018 \pm 0.040_{stat} \pm 0.007_{syst}$

with 2.5 fb^{-1} ➔ ± 0.015 stat

CPLEAR : $\zeta_{SL} = 0.4 \pm 0.7$

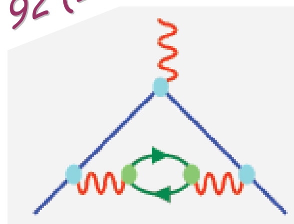
BELLE : $\zeta_{SL} = 0.029 \pm 0.057$

The hadronic cross section @ KLOE

a_μ :SM prediction vs experiment

measurement from E821 @ BNL $a_\mu = (g_\mu-2)/2 = 116\ 592\ 080(63) \times 10^{-11}$ PRL 92 (2004) 161802

theory : $a_\mu = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had}$ *Jegerlehner hep-ph/0703125*

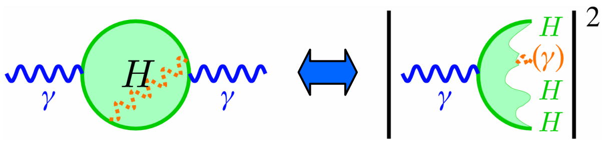


$a_\mu^{QED} = 116\ 584\ 718.11(16) \times 10^{-11}$

$a_\mu^{weak} = 154(1)_{had}(2)_{MH,Mt,3loop} \times 10^{-11}$

$a_\mu^{had} \approx 7000 \times 10^{-11}$ *the hadronic contribution gives the largest theory error*

- ✓ the low-energy contribution to a_μ^{had} cannot be obtained from p-QCD
- ✓ we measure $\sigma(e^+e^- \to \text{hadrons})$ and use dispersion integral



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

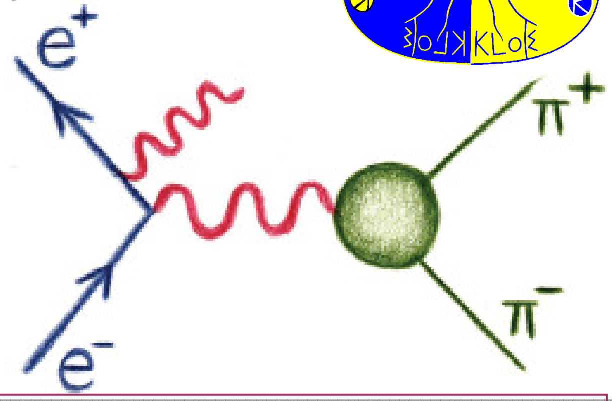
K(s) ~1/s

- ✓ $\sigma(e^+e^- \to \text{hadrons})$ is dominated below 1 GeV by $e^+e^- \to \pi^+\pi^-$
- ✓ and the $\pi\pi$ contribution to a_μ^{had} is ~ 66%

<u>so far, estimates of $\pi\pi$ contribution to a_μ^{had} from</u>

- ✓ measuring $\sigma(e^+e^- \to \pi^+\pi^-)$ vs $\sqrt{s}$ at an e^+e^- collider (CMD2 and SND @ VEPP-2M, $0.61 < \sqrt{s} < 0.96$ GeV, ~1% rel. uncertainty)
- ✓ using the spectral function from $\tau^\pm \to \pi^\pm\pi^0\nu_\tau$ (ALEPH, CESR data, Belle)
- ✓ at fixed $\sqrt{s}$ e^+e^- collider using *ISR* ➔ *KLOE @ DAΦNE*

From $\pi\pi\gamma$ to $\sigma_{\pi\pi}$ (method of radiative return)



exploit ISR to extract $\sigma(e^+e^- \to \pi^+\pi^-)$ for $M_{\pi\pi}$ from $2m_\pi \to \sqrt{s}$

- watch out for FSR: rate ~ same order as ISR signal
- include radiative corrections taking into account vacuum polarization

precise knowledge of the radiator function $H(M_{\pi\pi}^2)$

$$M_{\pi\pi}^2 \frac{d\sigma(\pi\pi\gamma, M_{\pi\pi}^2)}{dM_{\pi\pi}^2} = H(M_{\pi\pi}^2)\, \sigma(\pi\pi, M_{\pi\pi}^2)$$

$H(M_{\pi\pi}^2)$ includes radiative effects and kinematical cuts

QED MC calculation *(PHOKHARA, Karlsuhe theory group, Kuhn et al.)*

claimed precision: 0.5%

KLOE is its own luminosity monitor

$\int L\, dt$ from large-angle bhabha events $55^\circ < \theta_e < 125^0$ $\int L\, dt = (N_{obs} - N_{bkg})/\sigma_{eff}$

effective cross section from theory prediction + detector simulation

BABAYAGA generator, $\sigma_{eff} = 428.0(3)$ nb *[Calame et al. NP B758 (2006)]*

total systematic on luminosity 0.10% theo ⊕ 0.32% exp = 0.34%

EPJ C47 (2006)589

Measurement of $\sigma_{\pi\pi\gamma}$ @ small γ angles

two *high-θ* tracks from a vertex close to IP

compute photon momentum,
without explicit γ detection

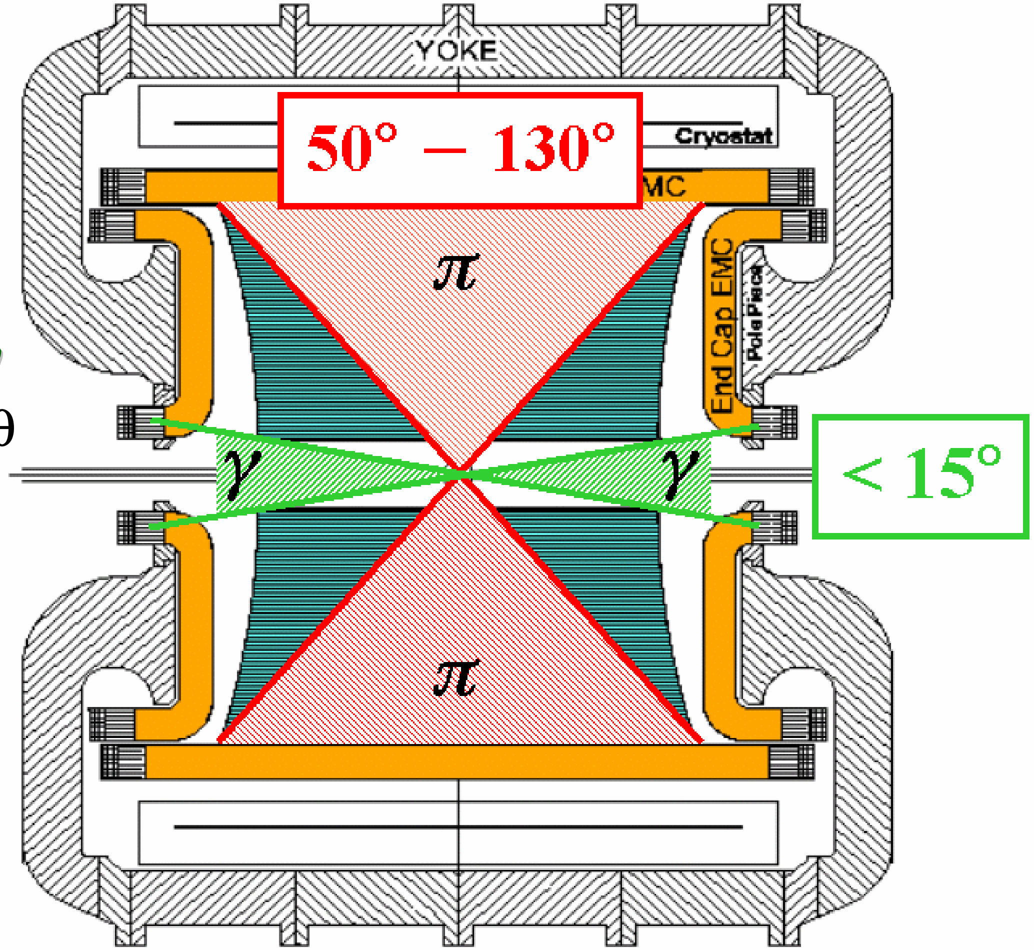
$p_\gamma = p_{e+} + p_{e-} - p_{\pi+} - p_{\pi-}$

select signal with a *small-θ photon* to enhance ISR: $d\sigma_{ISR}/d\Omega \sim 1/\sin^2\theta$

✓ relative contribution of FSR below the % level

✓ have no access to events with $M_{\pi\pi} < 600$ MeV

✓ reduce background from *$\pi^+\pi^-\pi^0$ to ≤ 10%*



residual background from $\pi^+\pi^-\pi^0$, $e^+e^-\gamma$, $\mu^+\mu^-\gamma$ subtracted using MC shapes

$\sigma_{\pi\pi\gamma}$ @ small γ angles : analysis

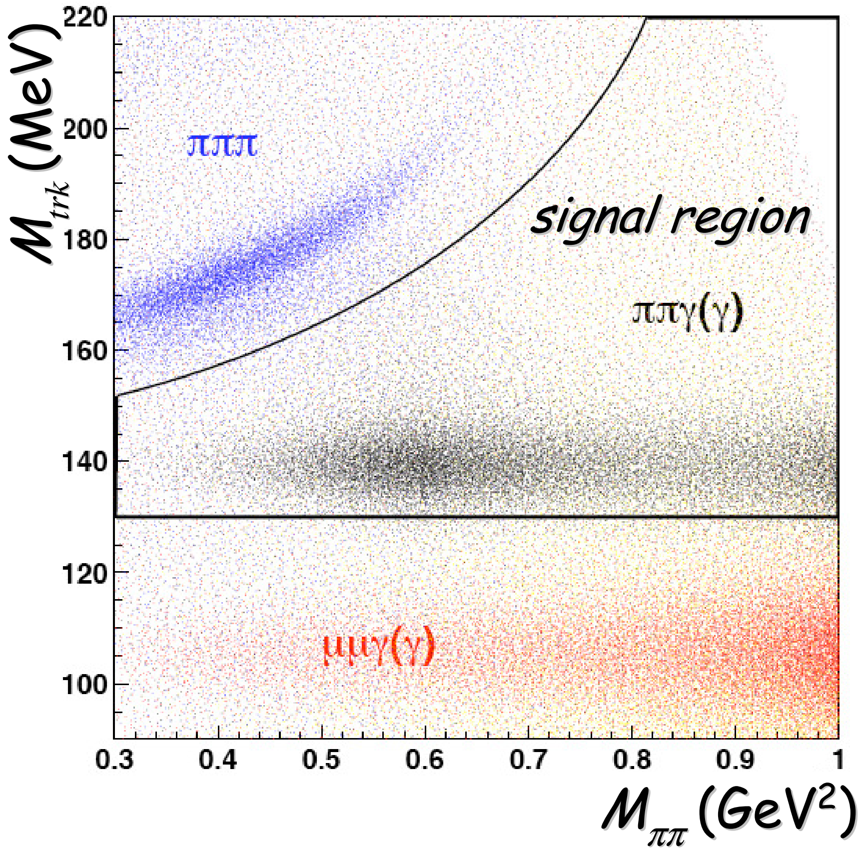
reject background using

1) kinematics: the M_{trk} variable

$$\left(\sqrt{s}-\sqrt{p_1^2+M_{trk}^2}-\sqrt{p_2^2+M_{trk}^2}\right)^2-(p_1+p_2)^2=0$$

to remove $\pi\pi\pi$ and $\mu\mu\gamma$ evts

2) PID from connected clusters (TOF + shape of energy deposit) to remove $e^+e^-\gamma$ evts



to get $\sigma(\pi\pi\gamma)$ in $M_{\pi\pi}$ bins

- ✓ evaluate & subtract residual bkg
- ✓ correct for angular acceptance
- ✓ correct for selection efficiency
- ✓ unfold for exp. resolution on $M_{\pi\pi}$
- ✓ normalize to luminosity

$\sigma_{\pi\pi\gamma}$ @ small γ angles : result

update of published analysis of 2001 data [PLB 606(2005)]

analysis of 2002 data

✓ trigger efficiency improved

✓ new generator BABAYAGA@NLO theory error from 0.5% to 0.1%

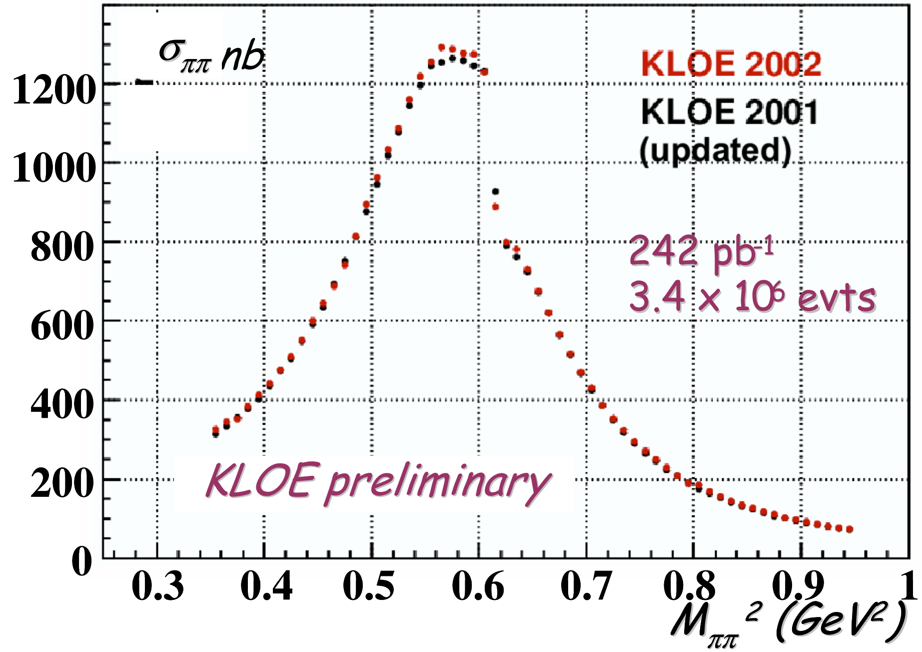
arXiv:0707.4078

<u>a_μ in the range 0.35-0.95 GeV^2 (10^{-11} units)</u>

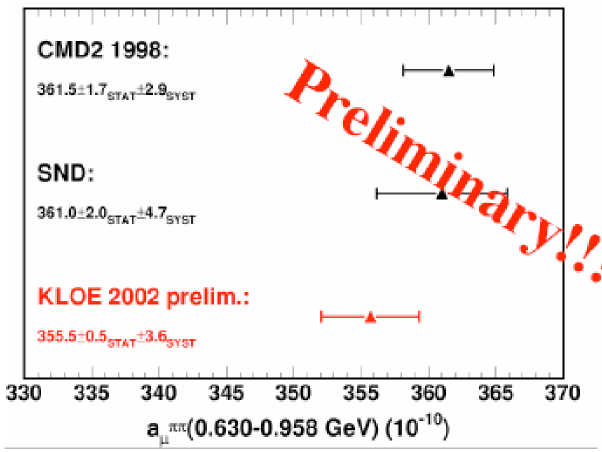
<u>2001</u> $a_\mu(0.35,0.95) = 3887(8)_{stat}(49)_{syst}$

<u>2001 update</u> $a_\mu(0.35,0.95) = 3844(8)_{stat}(49)_{syst}$

<u>2002</u> $a_\mu(0.35,0.95) = 3863(6)_{stat}(39)_{syst}$



CMD2 & SND @ VEPP-2M
PLB 648 (2007) 28



1) <u>discrepancy of e^+e^- vs τ data is confirmed</u>

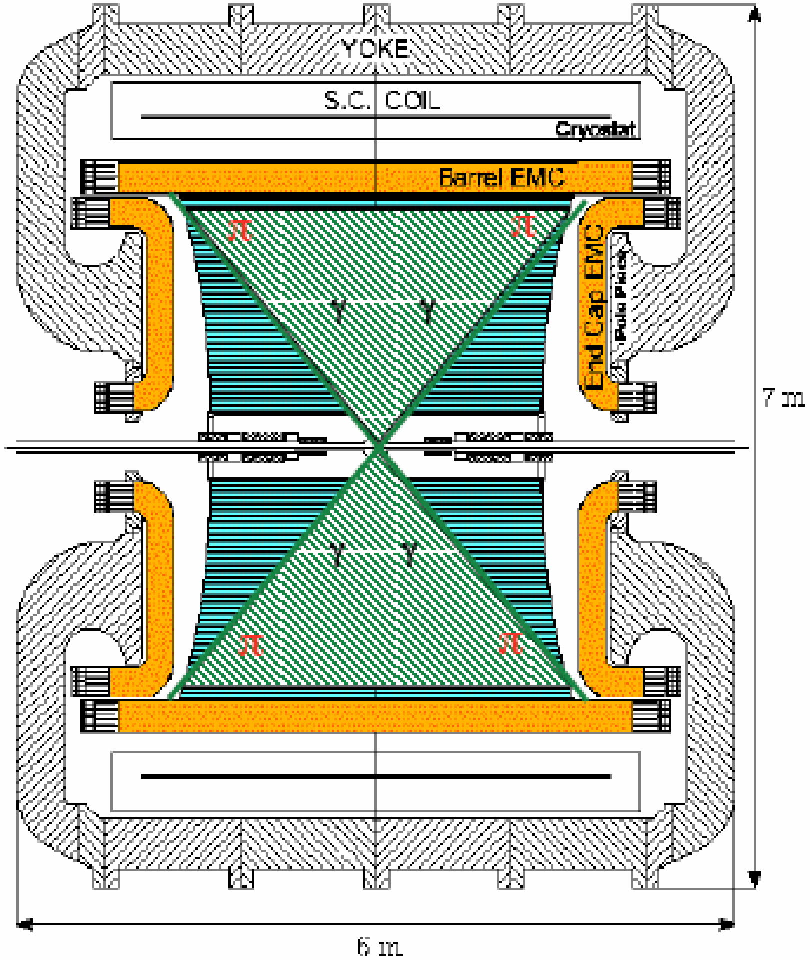
2) <u>difference of exp and SM is > 3σ</u>

$a_\mu(exp) - a_\mu(theory) = 287(91)10^{-11}$

Jegerlehner(hep-ph/0703125)

Measurement $\sigma_{\pi\pi\gamma}$ @ large γ angles

region close to threshold not accessible in SA analysis, but 20% of a_μ^{had} comes from region $M_{\pi\pi} < 600$ MeV



LA analysis

explicitly requires γ detection
with $E_\gamma > 50$ MeV in angular region
$50° < \theta_\gamma < 130°$ + two high-θ tracks
from a vertex close to IP

➔ *allows kinematic closure*

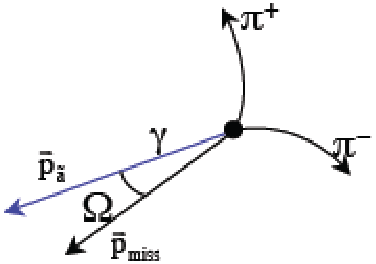
but …

- signal statistics is lower
- background from $\phi \to \pi^+\pi^-\pi^0$ is larger
- contribution of FSR is not *negligible anymore*
- *irreducibile* background from $\phi \to f_0(980)\gamma$

$\sigma_{\pi\pi\gamma}$ @ large γ angles : result

background rejection

- ~ 40% of bck from $\pi^+\pi^-\pi^0$ is rejected by <u>kinematic closure</u>
- further cut on angle between p_{miss} and detected γ



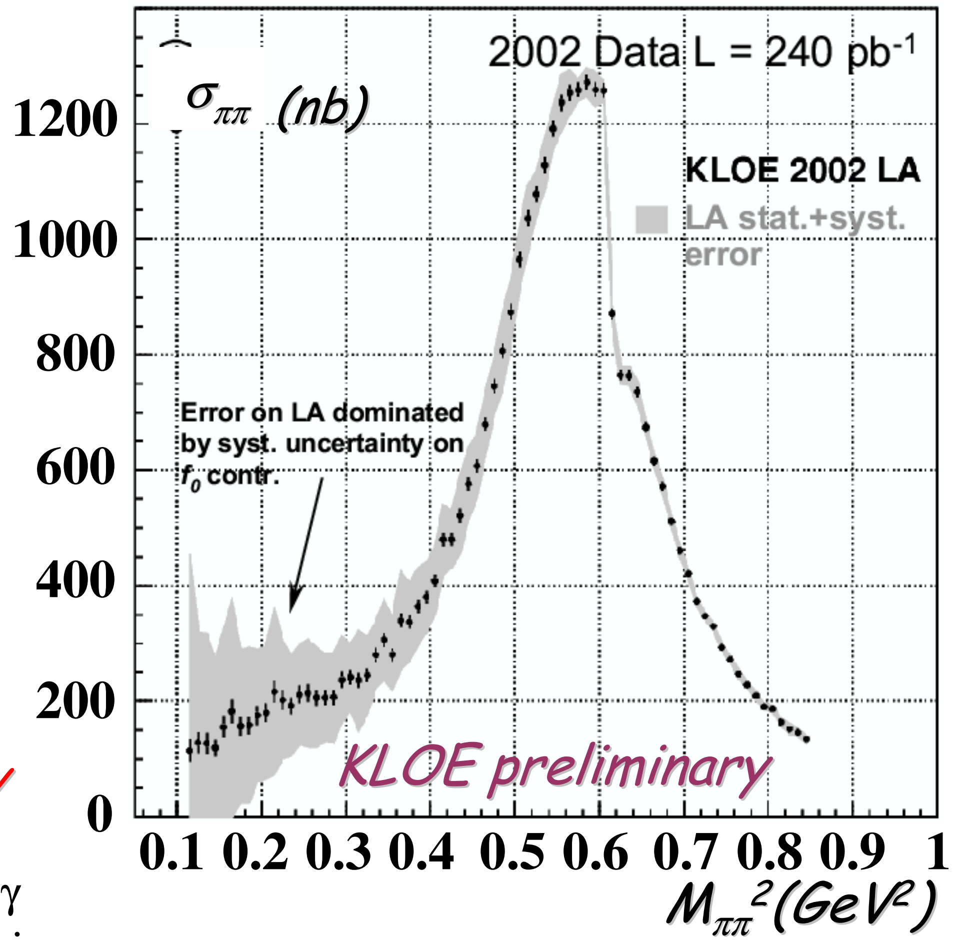
which is peaked at 0^0 for signal evts

background from $\mu\mu\gamma$ and $\pi\pi\pi$ well simulated by MC

irreducible bkg from $\phi \to f_0\gamma \to \pi\pi\gamma$

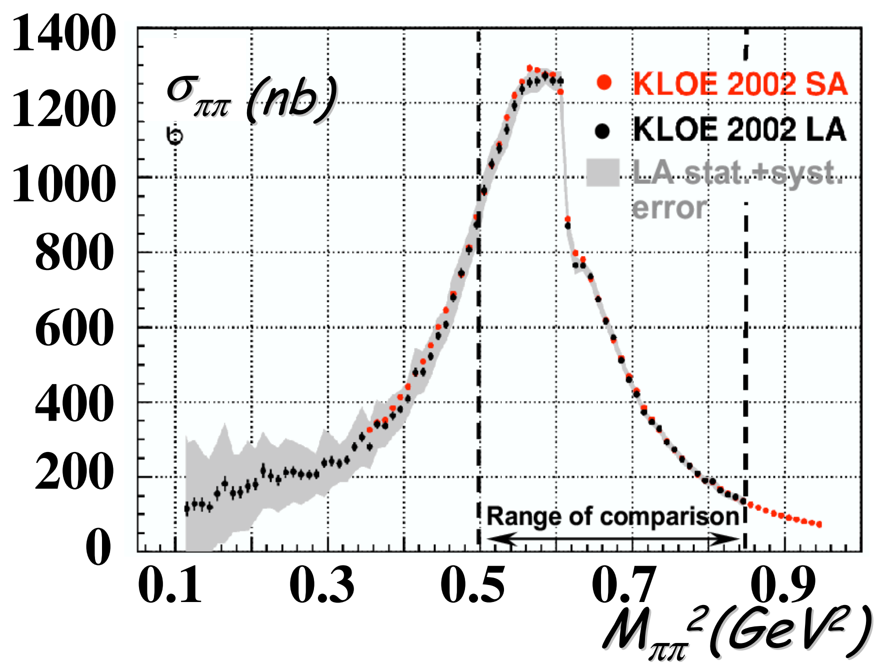
and FSR are the dominating uncertainty

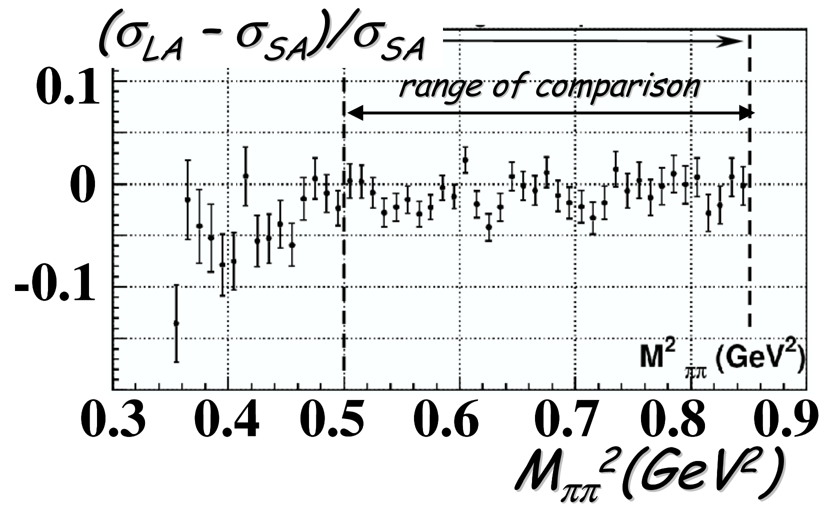
- use models for f_0 decays and results from dedicated KLOE analyses of $f_0\gamma \to \pi^0\pi^0\gamma$, $\pi^+\pi^-\gamma$
- the accuracy of the generator used to obtain FSR corrections is critical *(PHOKHARA)*



$\sigma_{\pi\pi\gamma}$ @ large γ angles : result

compare results from LA and SA in the range 0.5—0.85 GeV^2





(10^{-11} units)

from LA analysis $a_\mu(0.50—0.85) = 2525(6)_{stat}(51)_{syst}$ *60% of syst from f_0*

from SA analysis $a_\mu(0.50—0.85) = 2554(4)_{stat}(25)_{syst}$

Light meson spectroscopy @ KLOE

Scalar mesons physics

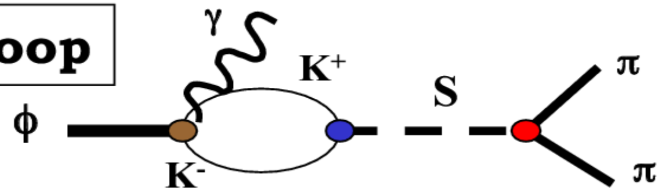
analyses of $\phi \to S\gamma$ decays: *$\pi^+\pi^-\gamma$, $\pi^0\pi^0\gamma$, $\eta\pi^0\gamma$ final states*

- large and partly unknown contributions from continuum, sizable interference
- both BR($\phi \to S\gamma$) and mass spectra are sensitive to scalar structure

450 pb^{-1} from 2001-2002 data → ~ 500k events for each mode

compare two fit models

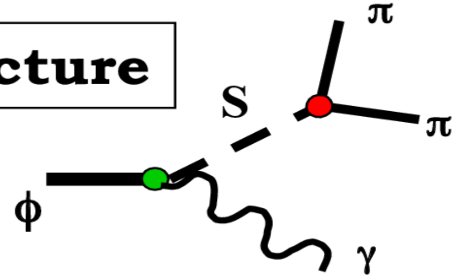
Kaon Loop



fit parameters M_S, $g_{S\pi\pi}$, g_{SKK}

[Achasov, Ivanchenko NPB315(1989), Achasov, Gubin PRD56(1997)]

No Structure



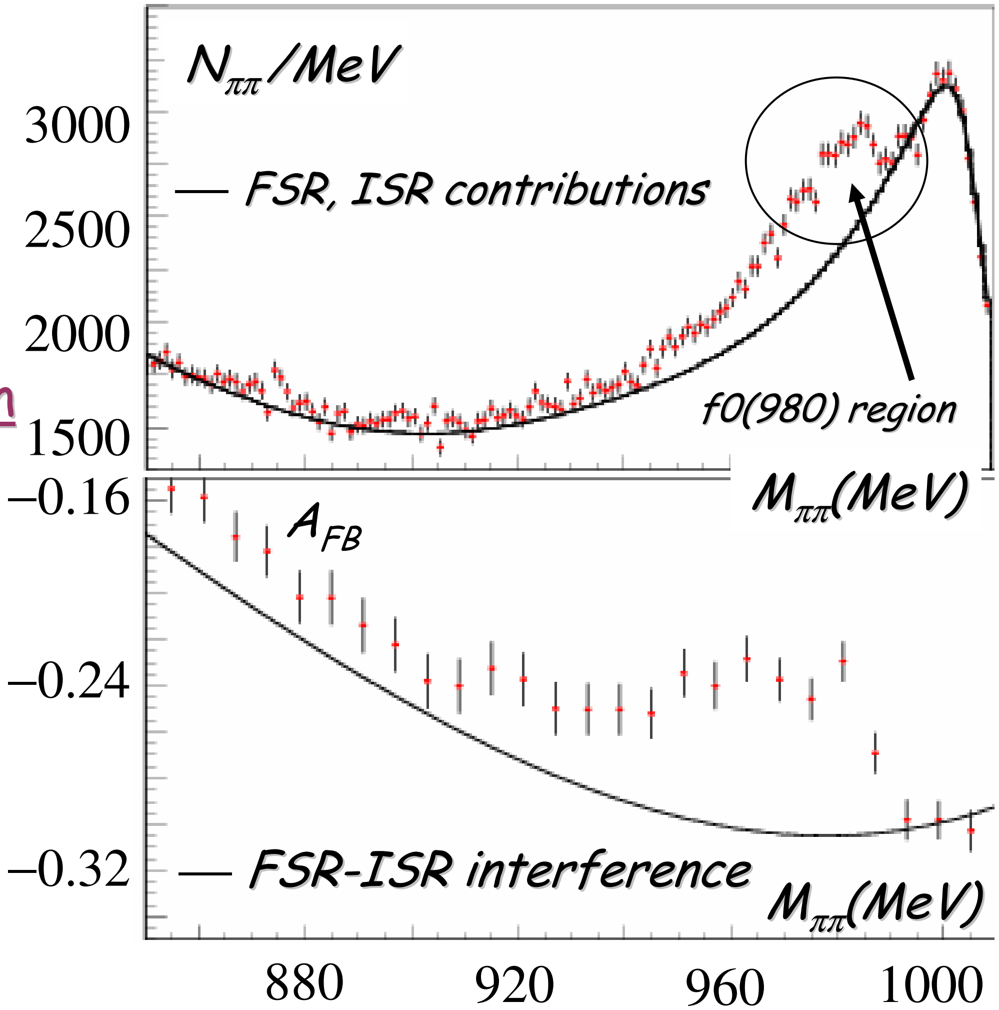
fit parameters M_S, $g_{S\pi\pi}$, g_{SKK}, $g_{S\phi\gamma}$

[Isidori, Maiani, Nicolaci, Pacetti JHEP 05(2006)]

The $f_0(980) \to \pi^+\pi^-$ final state

event selection

- 2 tracks with $\theta > 45^0$
- P_{miss} matching γ direction $\theta_\gamma > 45^0$
- $e^+e^-\gamma$ evts rejection on EmC basis
- $\mu^+\mu^-\gamma$ and $\pi^+\pi^-\pi^0$ suppressed with kinematical cuts



first evidence for f_0 contribution in mass spectrum

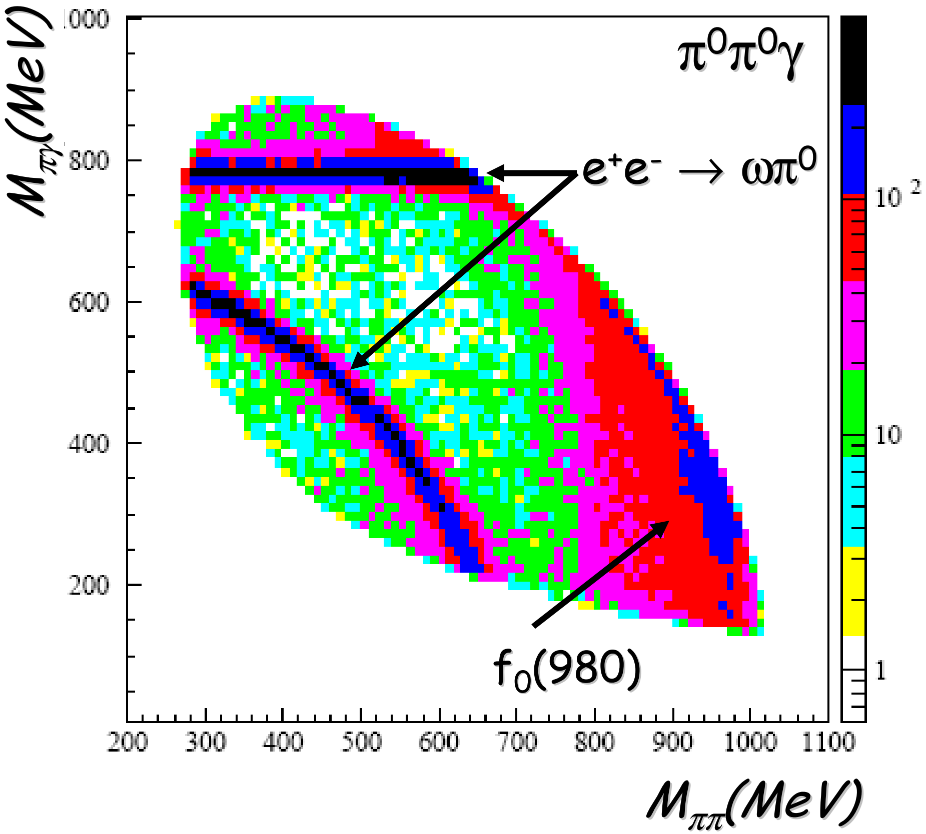
destructively interfering with FSR

the interference term between ISR and FSR is ODD under exchange of π^+ with π^-

$$A_{FB} = \frac{N_{\pi+}(\theta < 90^0) - N_{\pi+}(\theta > 90^0)}{N_{\pi+}(\theta < 90^0) + N_{\pi+}(\theta > 90^0)}$$

first evidence for f_0 contribution also from A_{FB}

The $f_0(980) \rightarrow \pi^0\pi^0$ final state



event selection

- 5 photons from the interaction point
- 1° kinematic fit with 4-momentum conservation
- 2° kinematic fit also with constraints on π^0 masses

Dalitz plot analysis to extract all possible contributions

- $e^+e^- \rightarrow \omega\pi^0$ interferes with ϕ-mediated production $\rightarrow$ dedicated analysis

$f_0(980) \to \pi^+\pi^- / \pi^0\pi^0$: results

Kaon Loop

Parameter	$\pi^+\pi^-\gamma$	$\pi^0\pi^0\gamma$
M_{f0} (MeV)	980—987	$976.8 \pm 0.3^{+0.9}_{-0.6} \pm 10.1$
g_{f0KK} (GeV)	5.0—6.3	$3.76 \pm 0.04^{+0.15}_{-0.08}{}^{+1.16}_{-0.48}$
$g_{f0\pi\pi}$ (GeV)	3.0—4.2	$-1.43 \pm 0.01^{+0.01}_{-0.06}{}^{+0.03}_{-0.60}$
$g^2_{f0KK} / g^2_{f0\pi\pi}$	2.2—2.8	$6.9 \pm 0.1^{+0.2}_{-0.1}{}^{+0.3}_{-3.9}$

No Structure

Parameter	$\pi^+\pi^-\gamma$	$\pi^0\pi^0\gamma$
M_{f0} (MeV)	973—981	$984.7 \pm 0.4^{+2.4}_{-3.7}$
g_{f0KK} (GeV)	1.6—2.3	$0.40 \pm 0.04^{+0.62}_{-0.29}$
$g_{f0\pi\pi}$ (GeV)	0.9—1.1	$1.31 \pm 0.01^{+0.09}_{-0.03}$
$g^2_{f0KK} / g^2_{f0\pi\pi}$	2.6—4.4	$0.09 \pm 0.02^{+0.44}_{-0.08}$
$g_{\phi a0\gamma}$ (GeV^{-1})	1.2—2.0	$2.61 \pm 0.02^{+0.31}_{-0.08}$

Parameter uncertainties

- $\pi^+\pi^-\gamma$ dominated by exp.
- $\pi^0\pi^0\gamma$ KL dominated by $\sigma(500)$ and $\pi\pi$ scattering inputs
- $\pi^0\pi^0\gamma$ NS dominated by fit instability

Kaon Loop $\pi^0\pi^0$: $\sigma(500)$ needed to describe the data
$\pi^+\pi^-$: not sensitive to $\sigma(500)$

No Structure both channels : only $f_0(980)$ sufficient to describe the data

always $g_{f0KK}^2 > g_{f0\pi\pi}^2$ except No Structure fit of $\pi^0\pi^0\gamma$

$BR(\phi \to S\gamma \to \pi^0\pi^0\gamma) = 1.07(7)10^{-4}$
EPJ C49:(2007) 473

$BR(\phi \to S\gamma \to \pi^+\pi^-\gamma) = 2.25(15)10^{-4}$
PLB 634:(2006) 148

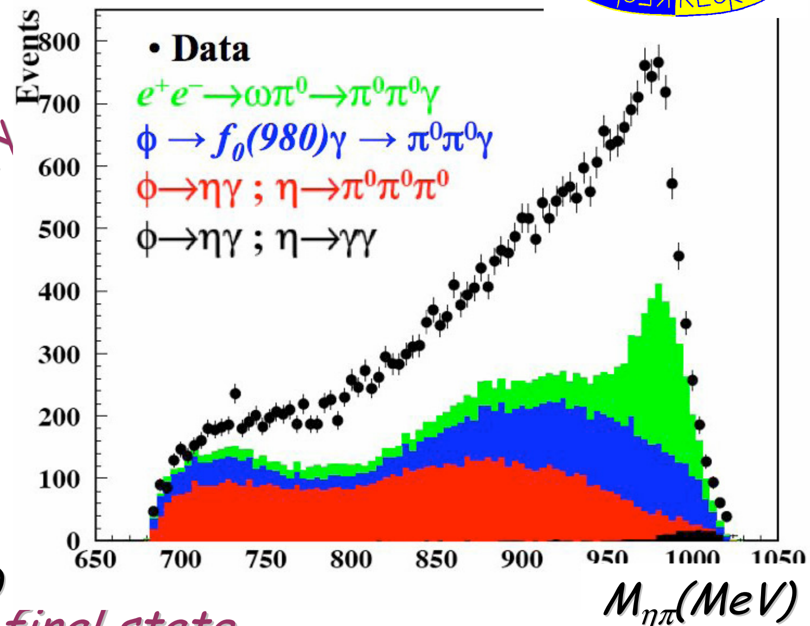
The $a_0(980) \to \eta\pi^0$ final state

$\eta \to \gamma\gamma$ final state

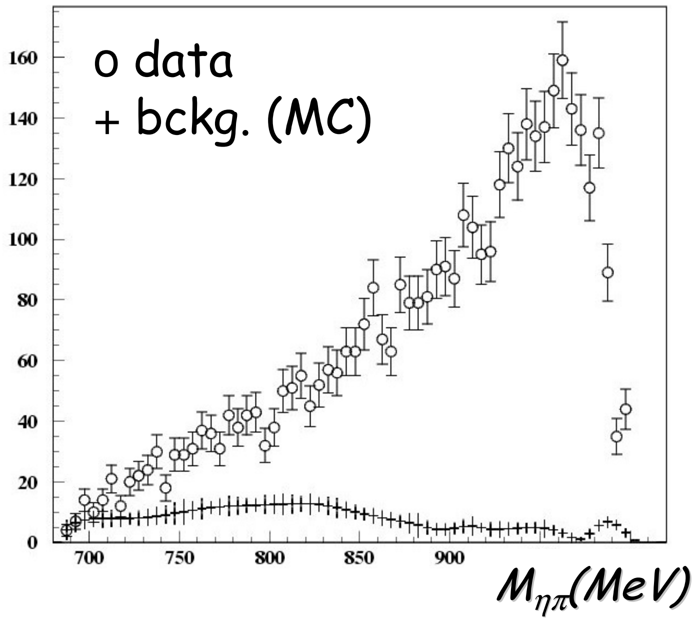
- 5 γ's from IP with $\theta_\gamma > 21^0$
- kinematic fit (4 - momentum conservation
  best γ pairing to π^0 and η)
- $3\text{x}10^4$ events from 414 pb^{-1}
- large background ~55% from final states with 5 or 7 γ's

$BR(\phi \to \eta\pi^0\gamma) = (6.92 \pm 0.10_{stat} \pm 0.20_{syst}) \times 10^{-5}$

KLOE Preliminary



ArXiv 070.4609



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

- 2 tracks + 5 γ's from IP with $\theta_\gamma > 21^0$
- kinematic fit (4 - momentum conservation
  best pairing to π^0 and η)
- $4.5\text{x}10^3$ events from 414 pb^{-1}
- small background ~15% from final states
  $e^+e^- \to \omega\pi^0 \to (\pi^+\pi^-\pi^0)\pi^0$
  $K_LK_S \to$ 2 tracks + 2,3π^0

$BR(\phi \to \eta\pi^0\gamma) = (7.19 \pm 0.17_{stat} \pm 0.24_{syst}) \times 10^{-5}$

KLOE Preliminary

$\eta - \eta'$ mixing

PLB 648:267-273(2007)

$\eta - \eta'$ system studied measuring the ratio R = BR($\phi \to \eta'\gamma$)/BR($\phi \to \eta\gamma$)

R can be related to the pseudoscalar mixing angle in the flavor basis and to the η' gluonic content

signal topology $\Rightarrow$

1. $\phi \to \eta'\gamma$, $\eta' \to \pi^+\pi^-\eta$, $\eta \to \pi^0\pi^0\pi^0$
2. $\phi \to \eta'\gamma$, $\eta' \to \pi^0\pi^0\eta$, $\eta \to \pi^+\pi^-\pi^0$

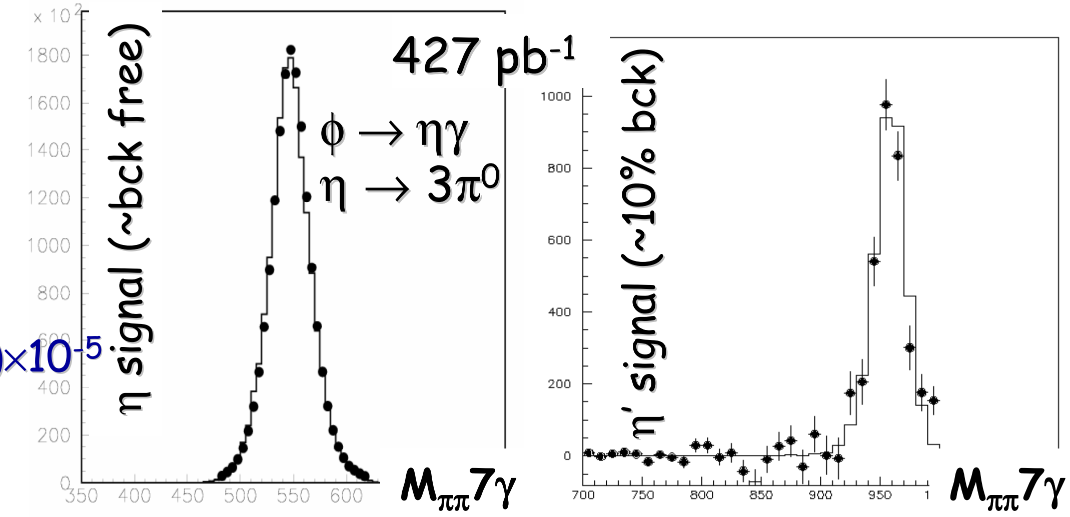
$\pi^+\pi^-7\gamma$ final state

the systematic error is dominated by the knowledge of the intermediate BR's

R = $(4.77 \pm 0.09_{stat} \pm 0.19_{syst})\times 10^{-3}$

BR($\phi \to \eta'\gamma$) = $(6.20 \pm 0.11_{stat} \pm 0.25_{syst})\times 10^{-5}$

BR($\phi \to \eta\gamma$) from PDG



in the quark-flavor basis mixing

EPJ C7 (1999) 271, PLB 503 (2001) 271

$$\begin{cases} |\eta\rangle = \cos\phi\,|u\bar{u} + d\bar{d}\rangle/\sqrt{2} + \sin\phi|s\bar{s}\rangle \\ |\eta'\rangle = -\sin\phi\,|u\bar{u} + d\bar{d}\rangle/\sqrt{2} + \cos\phi|s\bar{s}\rangle \end{cases}$$

$$\phi_P = (41.4 \pm 0.3_{stat} \pm 0.7_{sys} \pm 0.6_{th})^\circ$$

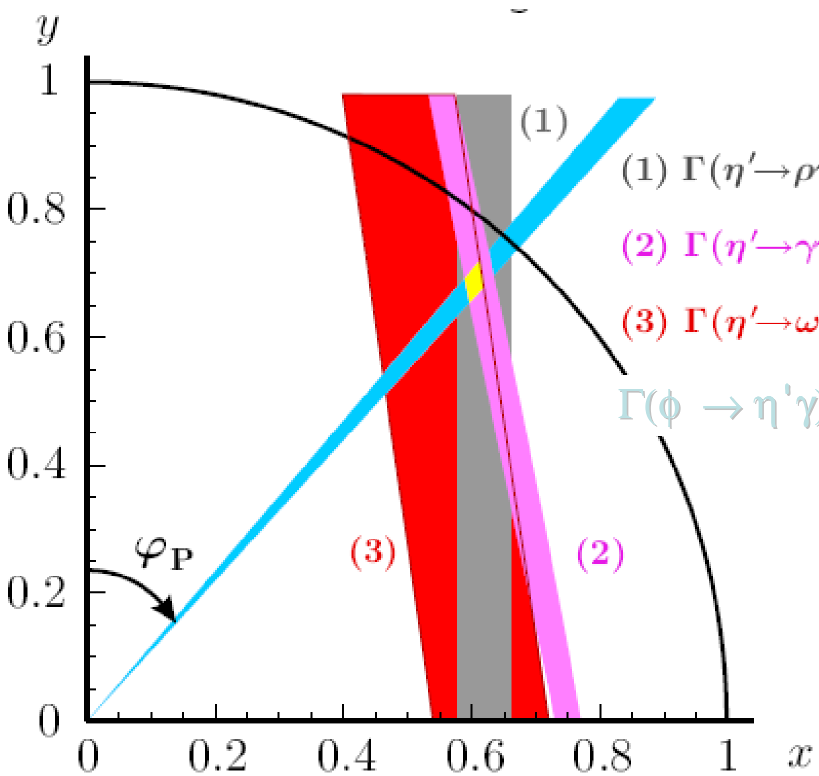
η' gluonium content

PLB 648:267-273(2007)

bound gluon states, gluonium, could mix in the η'

$$|\eta'\rangle = X|q\bar{q}\rangle + Y|s\bar{s}\rangle + Z|G\rangle$$

gluonium content means Z ≠ 0 that implies $(X^2 + Y^2) < 1$



allowing for gluonium in the η', a fit to our result R together with other measurements yields

$\varphi_p = (39.7 \pm 0.7)^0$

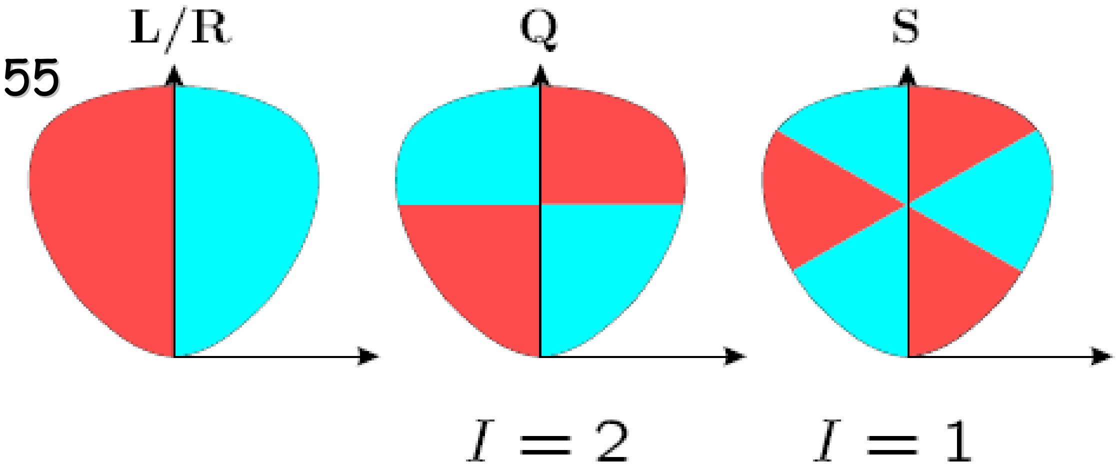
$Z^2 = 0.14 \pm 0.04$

$\chi^2/\text{Ndof} = 1.42/2$

$P(\chi^2) = 0.97$

Dalitz plot asymmetries in $\eta \to \pi^0\pi^+\pi^-$

ArXiv:0707.2355

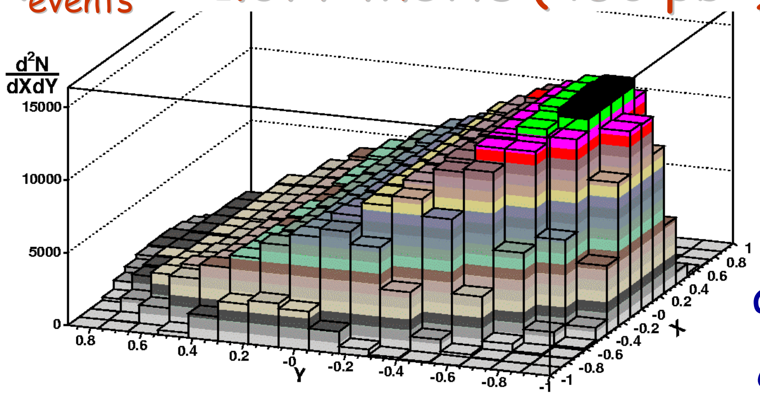


the Dalitz plot of this 3-body decay is described by two kinematic variables, defined in terms of the kinetic energies of the π's in the η rest frame

charge asymmetries

$$A_{LR} = \frac{N_1 - N_2}{N_1 + N_2} \qquad A_Q = \frac{N_1 + N_3 - N_2 + N_4}{N_1 + N_3 + N_2 + N_4} \qquad A_S = \frac{N_1 + N_3 + N_5 - N_2 + N_4 + N_6}{N_1 + N_3 + N_5 + N_2 + N_4 + N_6}$$

N_{events} = 1.377 Mevts (450 pb^{-1})



KLOE final

A_{LR} = (0.09 ± 0.10(stat) $^{+0.09}_{-0.14}$ (syst)) × 10^{-2}

A_Q = (-0.05 ± 0.10(stat) $^{+0.03}_{-0.05}$ (syst)) × 10^{-2}

A_S = (0.08 ± 0.10 (stat) $^{+0.08}_{-0.13}$ (syst)) × 10^{-2}

all asymmetries consistent with zero at 10^{-3} level

C-invariance OK

Conclusions

Kaon physics

- *comprehensive set of observables from K decays: BR's, τ's, λ's*
- *present accuracy on $|V_{US}|f_+(0)$ is < 0.3 % using only KLOE results*
- *lepton universality test from K_{l3} decays satisfied at < 0.5%*
- *sensitivity to NP effects from $K_{\mu 2}/\pi_{\mu 2}$*
- *R_K measured @ 3%*

Hadronic physics

- hadronic cross section
  - *discrepancy of e^+e^- vs τ data is confirmed*
  - *$a_\mu(exp) - a_\mu(theo) > 3\sigma$ important constraints on CMSSM ArXiv:0707.3447*
- light meson spectroscopy
  - *f_0 and a_0 parameters evaluated from a large data sample*
  - *η gluonium content studied*
  - *C-invariance studied in the $\eta \to \pi^+\pi^-\pi^0$ channel*
  - *most precise η mass measurement (I had not time to mention it !) ArXiv:0707.4616*

Much more to come from about x5 stat on tape !!

Spare slides

What's next ? KLOE2

A new scheme to increase DAΦNE luminosity by a factor O(5) has been proposed by P.Raimondi (*crabbed waist collisions*) – test in autumn 2007

If successful a new round of measurements with an improved KLOE detector could start in 2009

The KLOE detector has proven to well face the challenge, nevertheless ***something can be improved***:

- add an **inner tracker**
- add a **tagging system** for $e^+e^- \to e^+e^-\gamma\gamma$
- increase the **EMC read-out granularity**
- update / upgrade **the data acquisition**

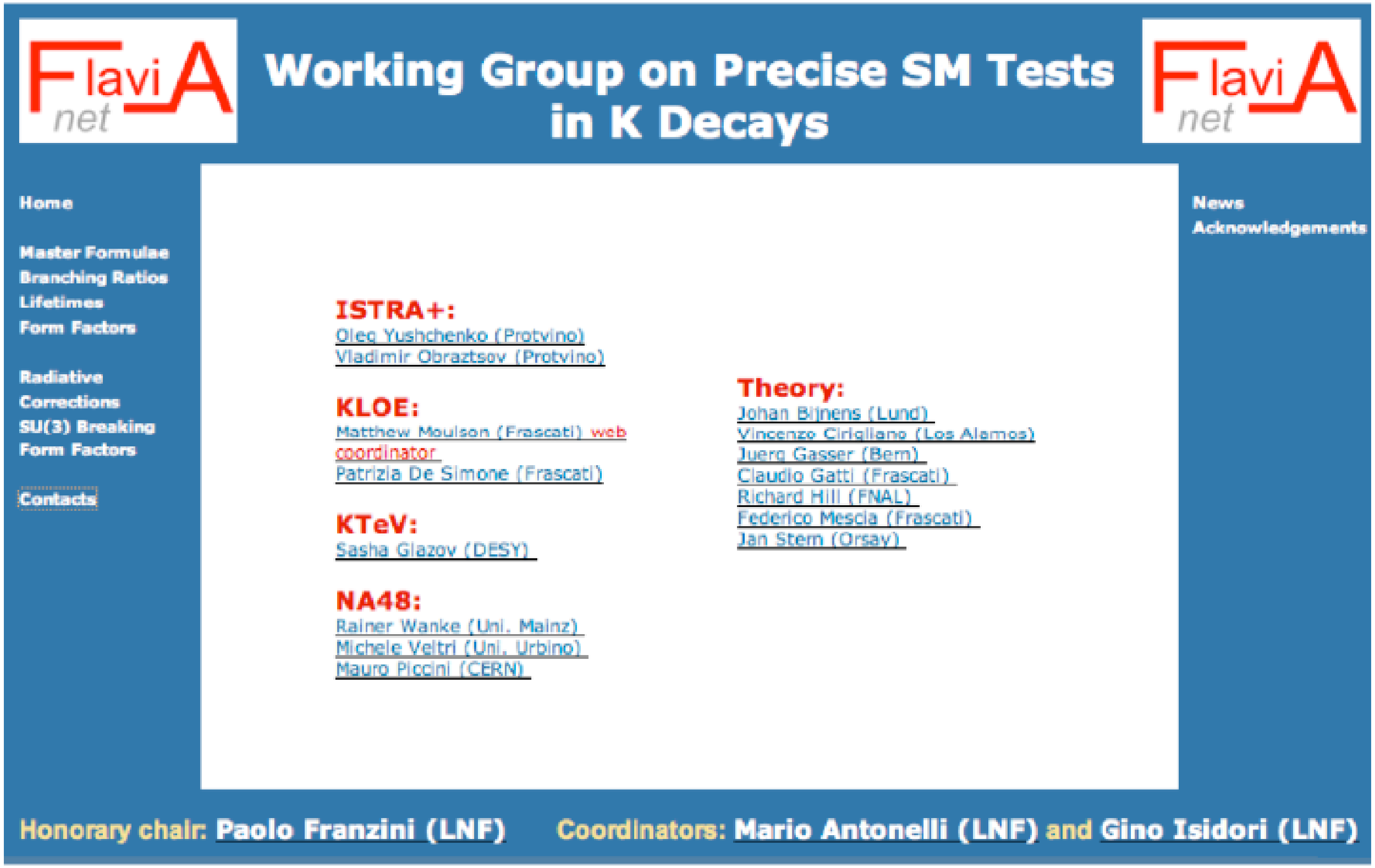
What's next ? KLOE2

- **Time evolution of entangled kaon states**, reach the sensitivity to the Planck scale: tests of CPT-symmetry and quantum mechanics
- **e–μ universality** ($K \rightarrow e\nu$ / $K \rightarrow \mu\nu$) and the **mass of the muon neutrino**
- **universality of the weak coupling** to leptons and quarks, CKM matrix unitarity
- **rare K_S decays** (semileptonic charge asymmetry, $K_S \rightarrow \pi^+\pi^-\pi^0$, $K_S \rightarrow \pi^0\pi^0\pi^0$)
- **light mesons**: structure of scalars (via $\gamma\gamma$ interaction), η and η' physics
- **$\sigma(e^+e^- \rightarrow$ hadrons)**, muon anomaly, evolution of α_{em}
- **baryon electromagnetic form factors**, $e^+e^- \rightarrow pp$, nn, $\Lambda\Lambda$
- *... and more*

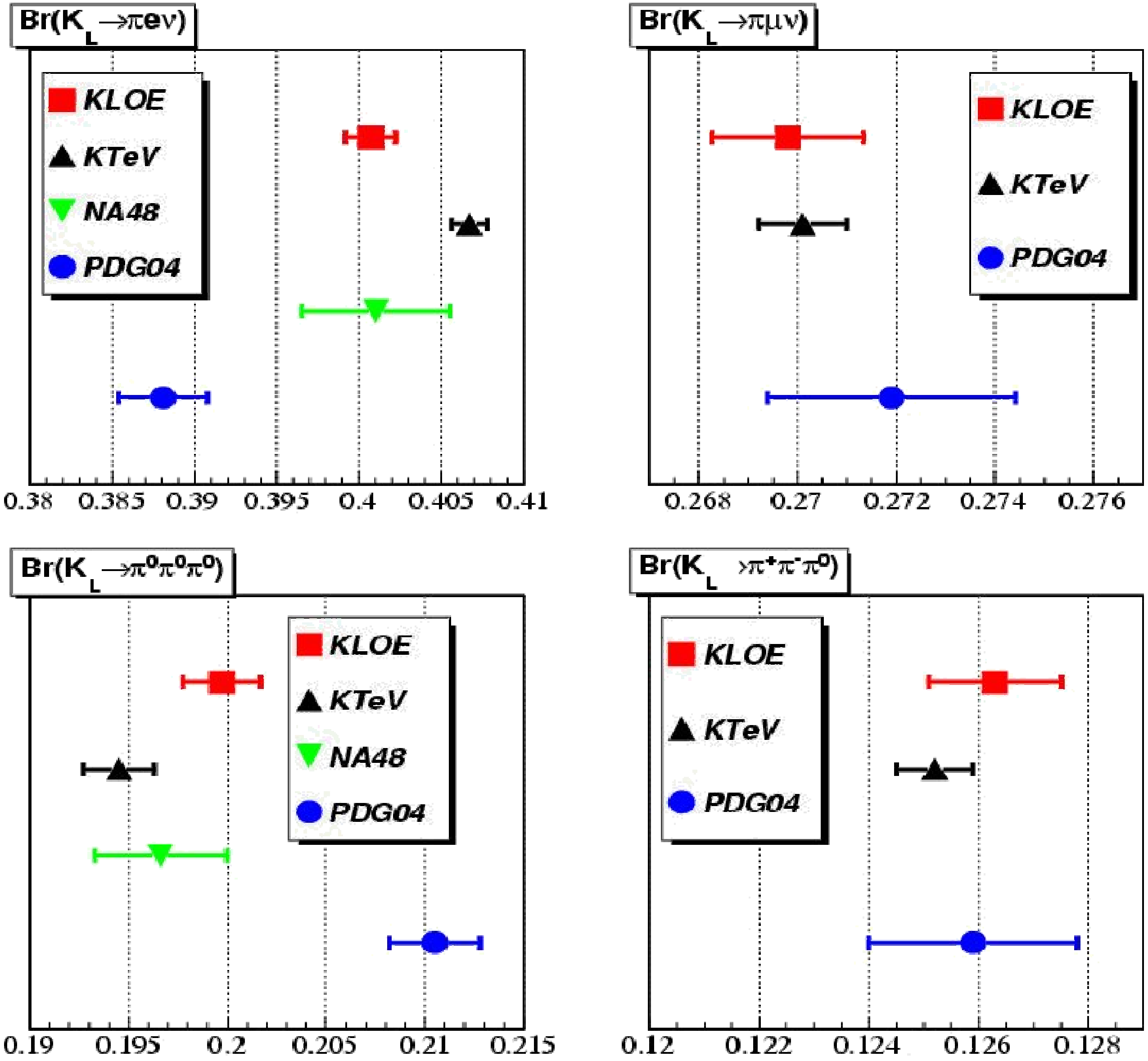
a new exciting challenge!
who wants to join us is welcome !!!

A WG for kaon physics

http://www.lnf.infn.it/wg/vus



K_L BR's comparison



First observation of $K_S \to \pi\mu\nu$

Measurement never done before

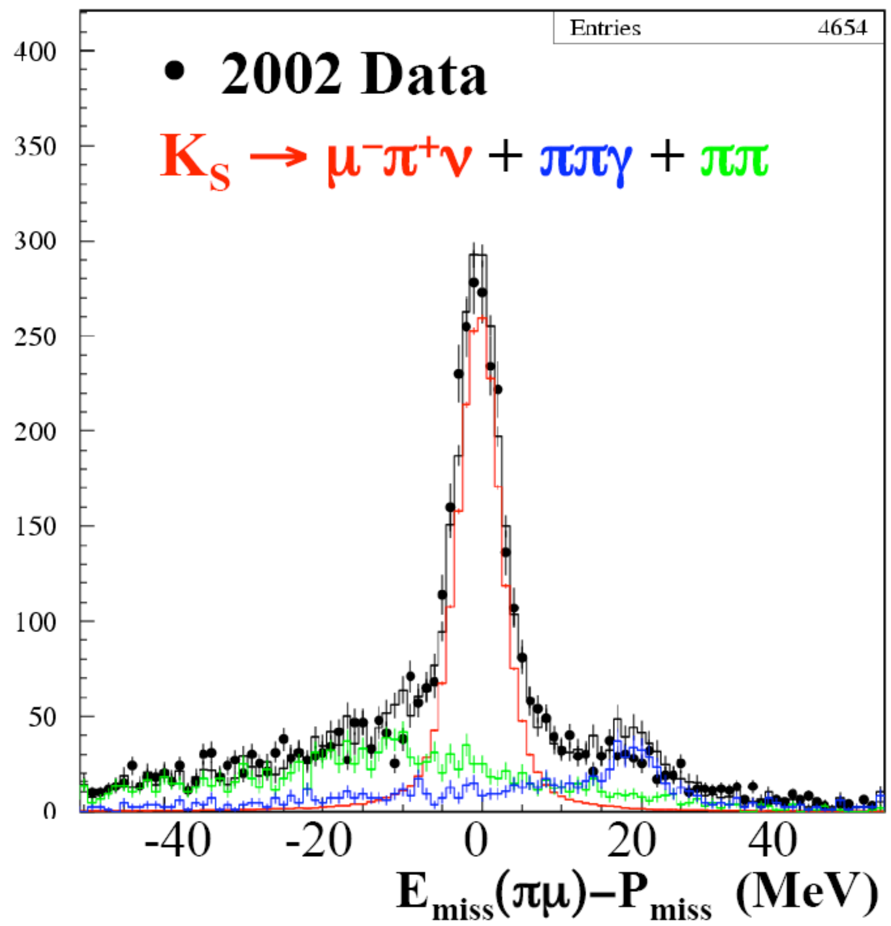
more difficult than K_{Se3}

- lower BR: expect 4×10^{-4}
- background events from

  $K_S \to \pi\pi$, $\pi \to \mu\nu$

  same PIDs of the signal
- event counting from the fit to $E_{miss}(\pi\mu) - P_{miss}$ distribution → ~ 3% stat error
- efficiency estimate from $K_{L\mu3}$ early decays and from MC + data control samples

Coming soon !!



$K_L \to \pi^+\pi^-$

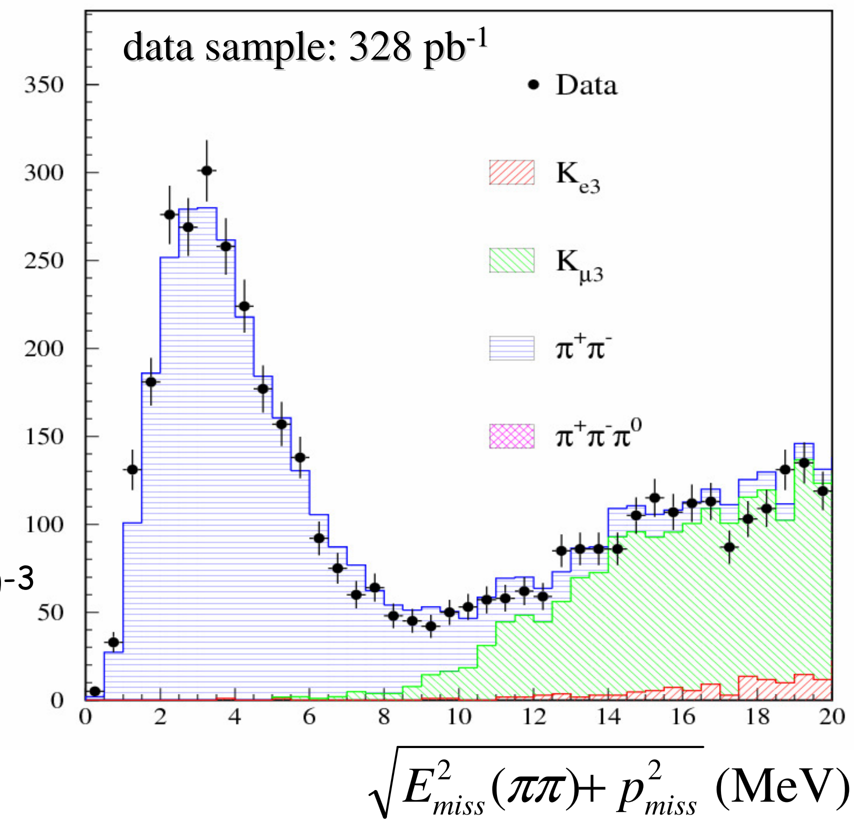
PLB 638(2006)140

signal selection:

- K_L beam tagged by $K_S \to \pi^+\pi^-$
- K_L vertex reconstructed in DC
- PID using decay kinematics
- fit with MC spectra

normalization using $K_L \to \pi\mu\nu$ events in the same data set

$BR(K_L \to \pi^+\pi^-) = (1.963 \pm 0.012 \pm 0.017) \times 10^{-3}$



- ➢ agreement with KTeV = $(1.975 \pm 0.012) \times 10^{-3}$
- ➢ confirms the discrepancy with

PDG04 = $(2.080 \pm 0.025) \times 10^{-3}$

using $BR(K_S \to \pi\pi)$ and τ_L from KLOE and τ_S from PDG04

$|\varepsilon| = (2.216 \pm 0.013) \times 10^{-3}$ PDG04 $|\varepsilon| = (2.280 \pm 0.013) \times 10^{-3}$

1.6σ agreement with prediction from Unitarity Triangle

R_K: perspectives toward 1% error

Present status	To complete analysis
1.1% Signal counts/1.7fb^{-1}	+30% of data under processing
	+40% w recover of prompt K decays
0.7% Bkg subtraction	× 2 rejection from kinematics
1.4% MC Bkg statistics	× 2 MC stat *under processing*
1.9% stat error	
1.5% incomplete PID CS coverage	× 4-8 CS stat available, loosen PID cut
0.9% one-prong CS stat	~ 0.5% using all data
0.9% TRG minimum-bias stat	Better control of trigger variables
2.0% syst error	

Will push error @ 1% : final result will be compared with P326/NA62 measurement (100k events) [R. Fantechi, EPS HEP 2007]

Kaon physics : future plans

1) Submit 8 papers → within 2007

- Complete K^+e2 → 2008*
- Form factor slopes for K^+e3 and $K^+\mu3$ decays → 2008

- Further improvements on V_{us}:
  - $K^+ \to \pi^+\pi^+\pi^-$ to close K^+ BRs → 2008
  - Update K_L lifetime to <0.5% → 2008
  - Update K_Se3 to 0.5% → to be started

- Update $\phi \to K_S K_L \to \pi^+\pi^-\pi^+\pi^-$ → 2008*
- Measurement of $K_S \to \pi^+\pi^- e^+e^-$ → 2008
- Update $K_S \to \pi^0\pi^0\pi^0$ and $K_L \to \gamma\gamma$ → 2008

- $K_L \to \pi\pi$ to <0.5% (+ improve on the main K_L / K^+ BRs) → to be started

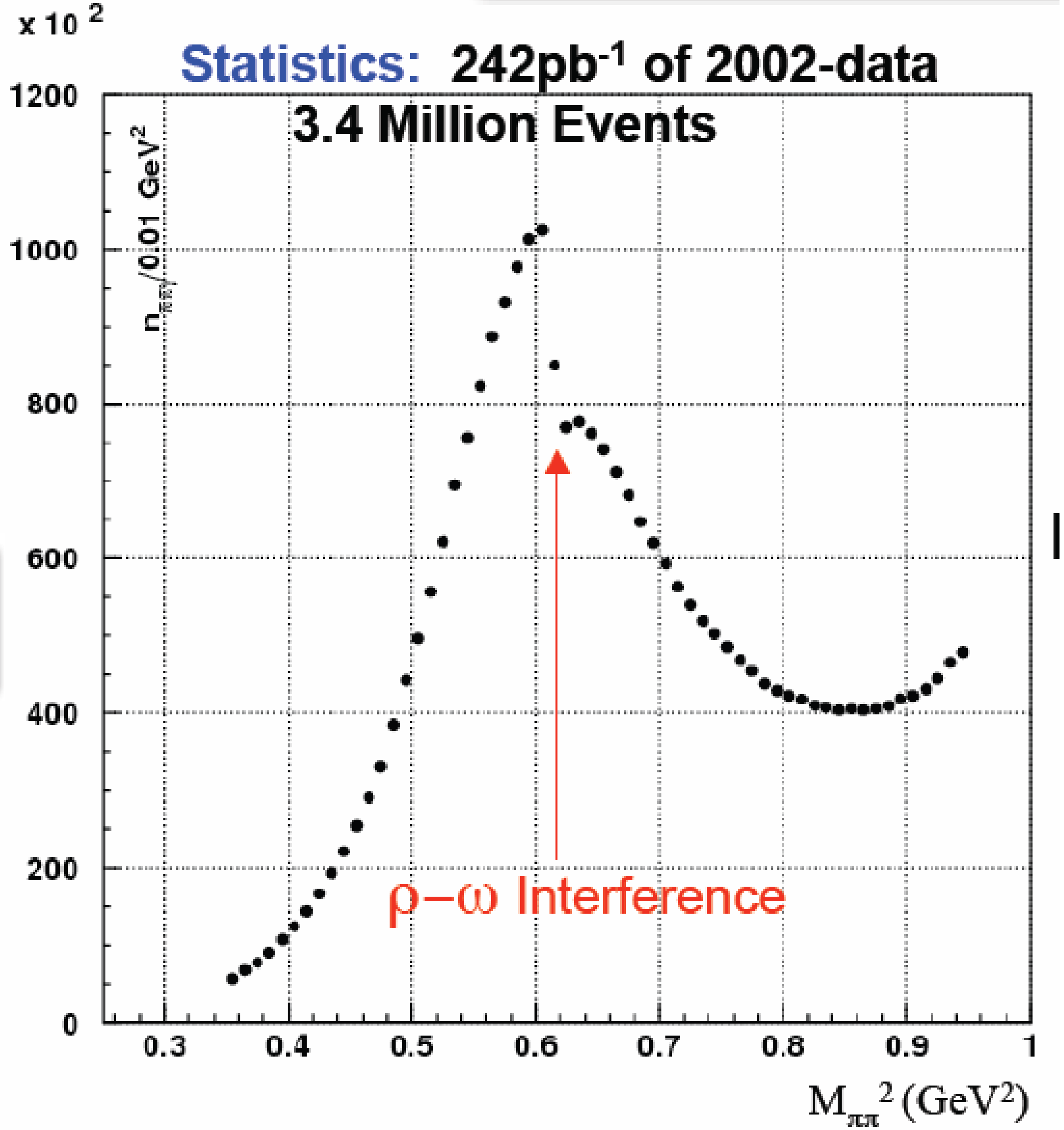
** preliminary result already presented*

$\sigma_{\pi\pi\gamma}$ @ small γ angles : analysis

to get $\sigma(\pi\pi\gamma)$ in $M_{\pi\pi}$ bins

- ✓ evaluate & subtract residual bkg
- ✓ correct for angular acceptance
- ✓ correct for selection efficiency
- ✓ unfold for exp. resolution on $M_{\pi\pi}$
- ✓ normalize to luminosity

$$\frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \frac{N^{obs} - N^{bkg}}{\Delta M^2_{\pi\pi}} \times \frac{1}{\varepsilon_{Select.}} \times \frac{1}{L}$$



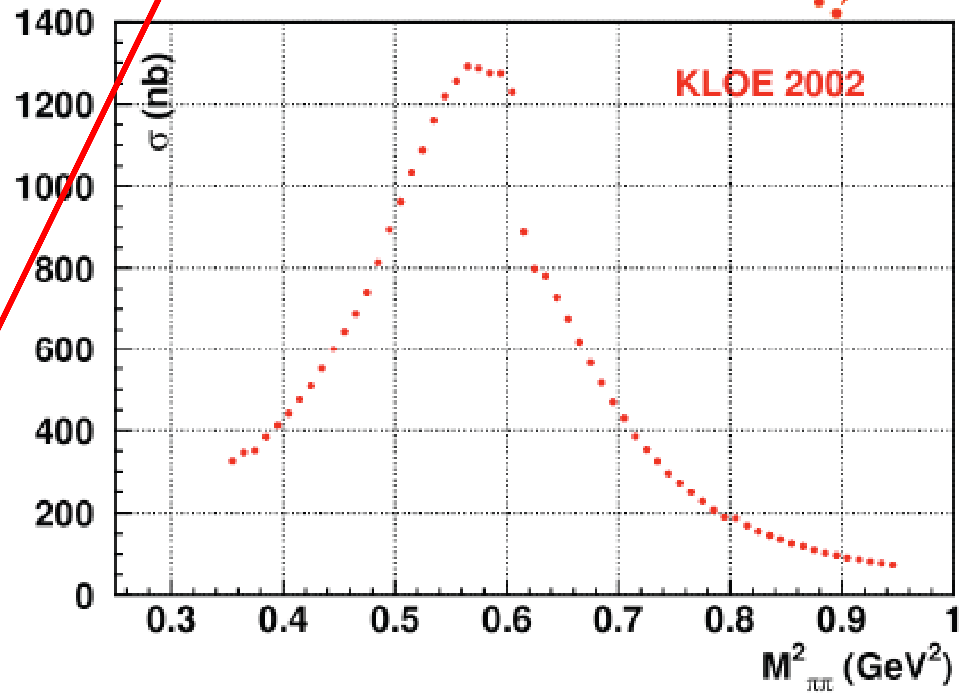
$\sigma_{\pi\pi\gamma}$ @ small γ angles : result

Preliminary!!!

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

was 0.6% in previous analysis

Offline Filter	negligible
Background	0.3%
Trackmass/Miss. Mass	0.2% (prelim)
π/e-ID	0.3%
Vertex	0.5%
Tracking	0.4%
Trigger	0.2%
Acceptance (θ_π)	negligible
$M_{\pi\pi}^2 \rightarrow M_{\gamma*}$ (FSR corr.)	0.3% (prelim)
Software Trigger	0.1 %
Luminosity	0.3%
Acceptance (θ_{Miss})	0.1%
Radiator H	0.5%
Vacuum polarization	negligible



Σ_{Total} = **1.1%** *was 1.3% in previous analysis*

$\sigma_{\pi\pi\gamma}$ @ large γ angles : asimmetry

In the case of a non-vanishing FSR contribution, the interference term between ISR and FSR is odd under exchange $\pi^+ \leftrightarrow \pi^-$ .This gives rise to a non-vanishing ***forward-backward asymmetry***:

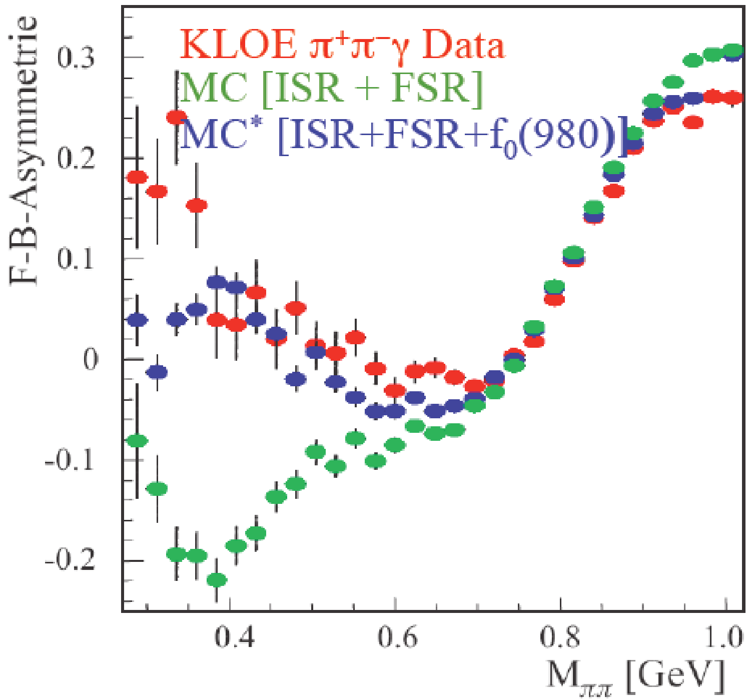
Binner, Kühn, Melnikov, Phys. Lett. B 459, 1999

$$A = \frac{N(\theta^+ > 90^o) - N(\theta^+ < 90^o)}{N(\theta^+ > 90^o) + N(\theta^+ < 90^o)}$$

➔ check the validity of the FSR model (Phokhara uses sQED, *i.e.* pointlike pions)

➔ in a similar way, radiative decays of the ϕ into scalar mesons decaying to $\pi^+\pi^-\gamma$ contribute to the charge asymmetry

Czyz, Grzelinska, Kühn, hep-ph/0412239

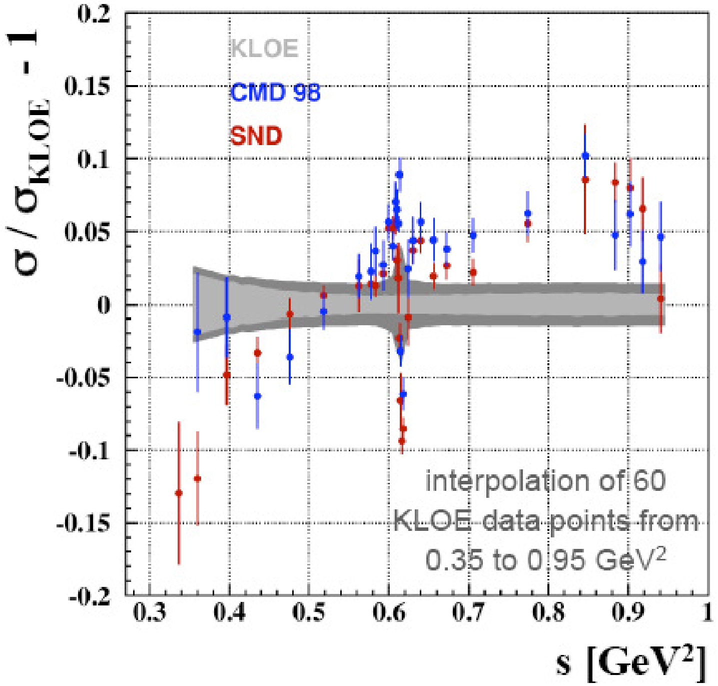


*G. Pancheri *et. al.*, arXiv:0706.3027

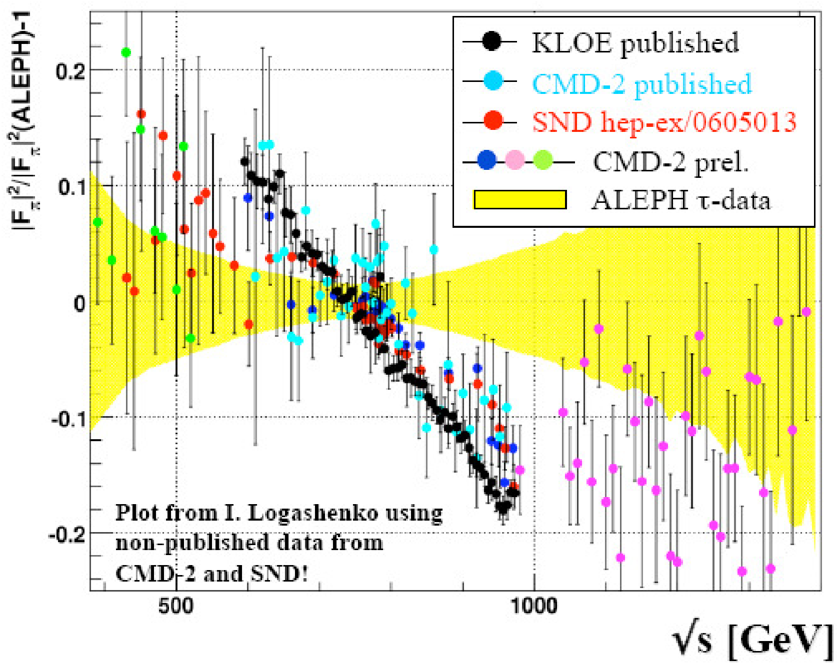
<u>Possibility to study the properties of scalar mesons with charge asymmetry</u>

Comparison between e^+e^- and τ data

Relative difference btw.
KLOE (2001) and CMD-2, SND



Relative difference btw. e^+e^- Data
and τ-spectral function from ALEPH



→KLOE confirmed the CMD-2 discrepancy with tau data and "...devalidates the use of τ-data until a better understanding of the discrepancies is achieved" (A. Höcker ICHEP-04)

→Some disagreement btw. KLOE and SND/CMD-2 seen at low and high masses

→ **All recent e+e- experiments agree now within 0.5σ in the 2π-contribution to a_μ^{had}**

→ Waiting for new results from e^+e^- and τ data (Belle)

Scalar and pseudoscalar mesons

$e^+e^- \to \phi \to \omega\pi^0$ cross section*	ArXiv:0707.4130
$\phi \to a_0(980)\,\gamma \to \eta\,\pi^0\,\gamma$	ArXiv:0707.4609
UL on $\phi \to K^0\bar{K}^0\gamma$ **	ArXiv:0707.4148

η mass	ArXiv:0707.4616
$\eta \to \pi^0\pi^0\,\pi^0$ Dalitz parameters	ArXiv:0705.4137
$\eta \to \pi^+\pi^-\,\pi^0$ Dalitz parameters	ArXiv:0707.2355
$\eta-\eta'$ mixing and η' gluonium content	PLB 648 (2007)

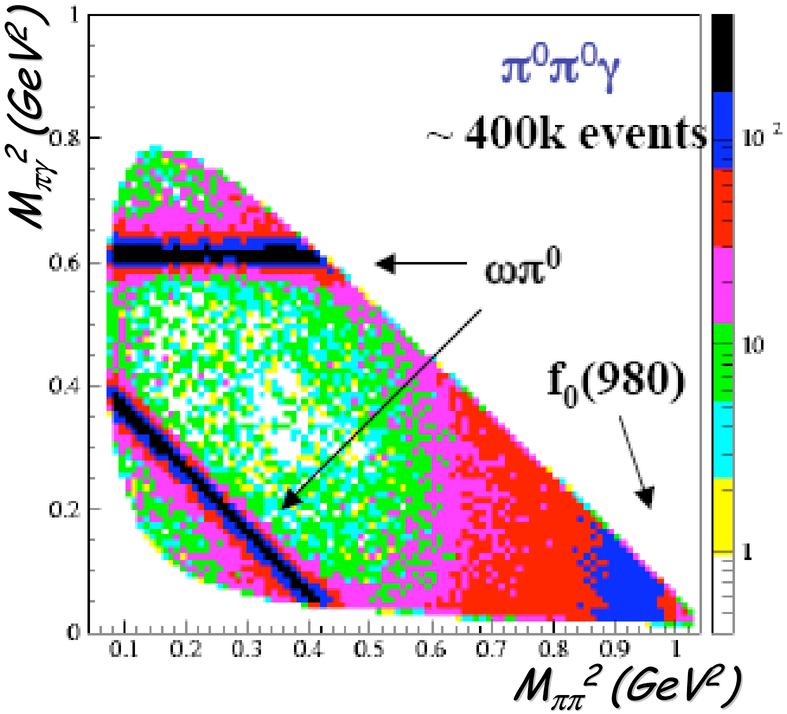
* energy scan 2006

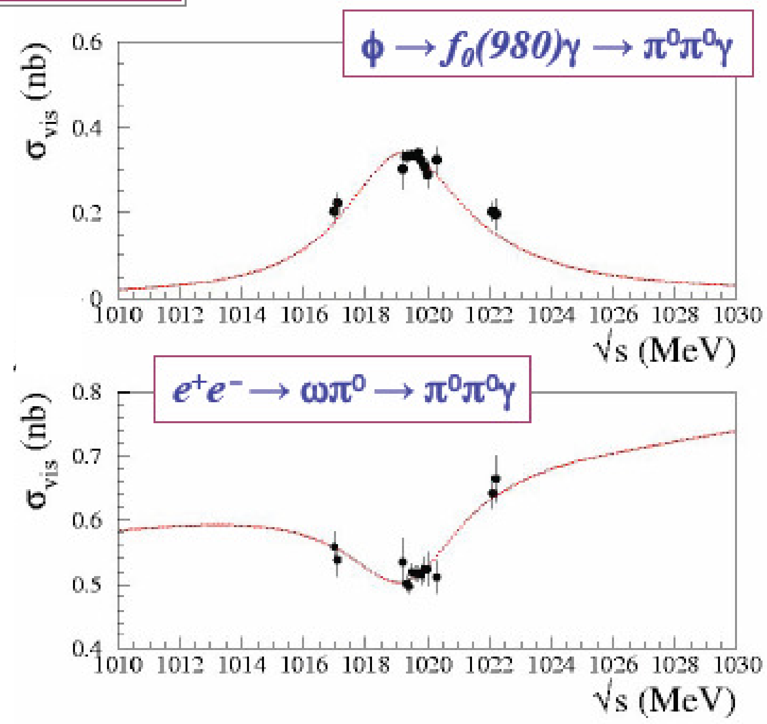
** whole data sample

The $f_0(980) \to \pi^0\pi^0$ final state

event selection

- 5 photons from the interaction point
- 1° kinematic fit with 4-momentum conservation
- 2° kinematic fit also with constraints on π^0 masses





Dalitz plot analysis to extract all possible contributions

- $e^+e^- \to \omega\pi^0$ interferes with ϕ-mediated production $\to$ dedicated analysis
- line shape for non-ω-mediated final state shows resonant behavior

The $a_0(980) \to \eta\pi^0$ fit results

$a_0(980)$ parameters extracted from a simultaneous fit to both $M_{\eta\pi}$ spectra (efficiency + resolution accounted)

free parameters:

Ratio $BR_{\eta \to \gamma\gamma} / BR_{\eta \to \pi+\pi-\pi0}$

$BR(\phi \to \rho\pi^0 \to \eta\pi^0\gamma)$

KL:

M_{a0}, g_{a0KK} $g_{a0\eta\pi}$ couplings

NS:

M_{a0}, $g_{\phi a0\gamma}$ g_{a0KK} $g_{a0\eta\pi}$ couplings

Parameter	Kaon Loop	No Structure
M_{a0} (MeV)	983 ± 1	983 (fixed)
g_{a0KK} (GeV)	**2.16 ± 0.04**	**1.57 ± 0.13**
$g_{a0\eta\pi}$ (GeV)	2.8 ± 0.1	2.2 ± 0.1
$g_{\phi a0\gamma}$ (GeV^{-1})	**–**	**1.61 ± 0.05**
$BR(\phi\to\rho\pi\to\eta\pi\gamma)\times10^6$	0.9 ± 0.4	4.1 (fixed)
$BR(\eta\to\gamma\gamma)/BR(\eta\to\pi\pi\pi)$	**1.69 ± 0.04**	**1.69 ± 0.04**
χ^2/Ndf	**156.6/136**	**146.8/134**
$P(\chi^2)$	**11%**	**21%**

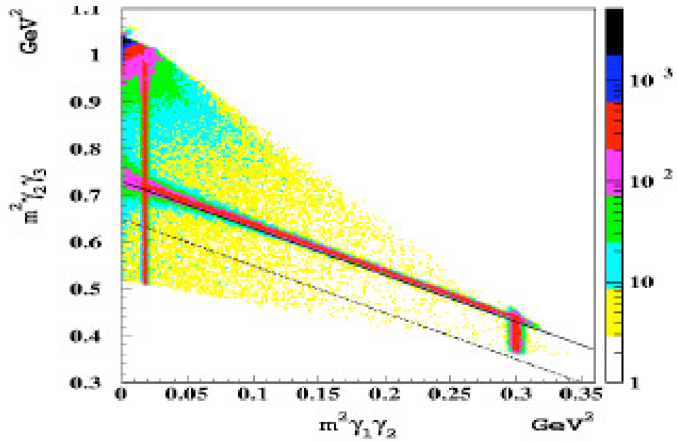
KLOE Preliminary ArXiv 0707.4609

in agreement with PDG06

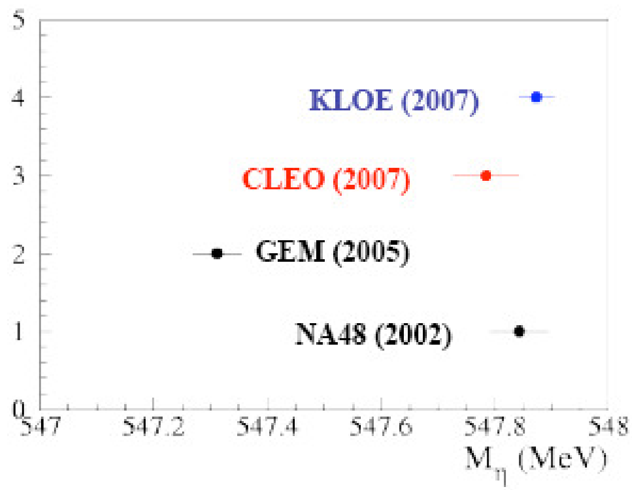
sizable *s* quark content

η mass measurement

- We select $\phi \rightarrow \eta\gamma \rightarrow 3\gamma$
- Mass scale checked with $M_{\pi 0}$: 1.4 σ from PDG06



systematic effect	m_η (keV)	m_{π^0} (keV)
Calorimeter energy scale	4	1
Calorimeter not linearity	4	11
Vertex position	4	6
Angular uniformity ϕ	15	12
Angular uniformity θ	10	44
ISR effect	8	9
Dalitz plot cut slope	12	4
Dalitz plot cut constant	12	1.9
χ^2 cut	0.7	4
overall	27	49



M_η = (547.873 ± 0.007 ± 0.031) MeV

arXiv:0707.4616

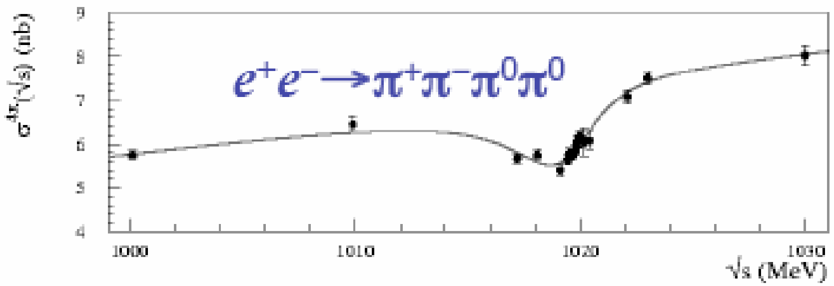
$e^+e^- \to \phi \to \omega\pi^0$

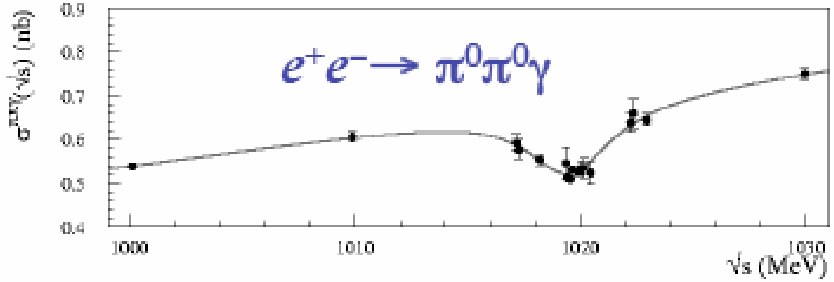
- Cross section and BR($\phi \to \omega\pi$) from 2006 energy scan
- Interference with continuum
- Parametrization needed

$$\sigma(\sqrt{s}) = \sigma_0(\sqrt{s}) \cdot \left|1 - Z\frac{M_\phi \Gamma_\phi}{D_\phi}\right|$$

Model indep. $\sigma_0(\sqrt{s})$:

$$\sigma_0(\sqrt{s}) = \sigma_0 + \sigma'(\sqrt{s} - M_\phi)$$





Parameter	$\pi^+\pi^-\pi^0\pi^0$	$\pi^0\pi^0\gamma$
σ_0^i (nb)	8.12 ± 0.14	0.776 ± 0.012
$\Re_i(Z)$	0.097 ± 0.012	0.013 ± 0.013
$\Im_i(Z)$	-0.133 ± 0.009	-0.155 ± 0.007
σ'_i (nb/MeV)	0.072 ± 0.008	0.0079 ± 0.0006
χ^2/Ndf	**13.4/13**	**12.8/15**

$$BR(\phi \to \omega\pi^0) = \frac{\sigma_0^{\omega\pi}|Z_{4\pi}|^2}{\sigma_\phi} = (5.63 \pm 0.70) \times 10^{-5}$$

$$\mathrm{SND(2000): BR}(\phi \to \omega\pi^0) = (5.2^{+1.3}_{-1.1}) \times 10^{-5}$$

Search for $\phi \to K^0\overline{K}^0\gamma$

Mainly proceed through $\phi \to [f_0(980)+a_0(980)]\gamma \to K^0\overline{K}^0\gamma$

Never observed

1.4 fb^{-1} data, equivalent MC statistics for background

channel: $K_S K_S\gamma \to \pi^+\pi^-\pi^+\pi^-\gamma$

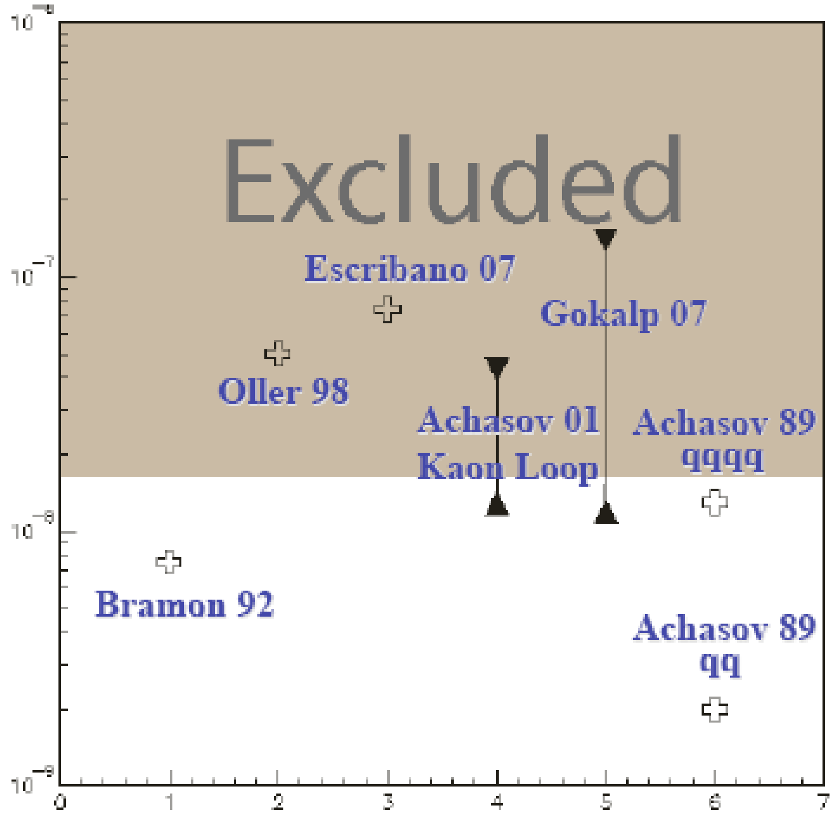
background: $K_S K_L$ + ISR/FSR γ

Selection cuts optimized on MC

N(data)=1, N_{bkg}(MC) = 0

$BR(\phi \to K^0\overline{K}^0\gamma) < 1.8 \times 10^{-8}$ @ 90% CL

arXiv:0707.4148



$\sigma(e^+e^- \to$ had): future plans

• Complete the small angle analysis: still missing is the unfolding of detector resolution.

• Measure pion form factor via bin-by-bin ratio of $\pi^+\pi\gamma/\mu^+\mu^-\gamma$ cross sections $\to$ no need of luminosity, radiator function, vacuum polarization correction

$\to$ early 2008

• Obtain pion form factor from data taken at $\sqrt{s}$ = 1 GeV $\to$ suppression of background from ϕ decays (f_0), which spoil accuracy of large angle analysis close to the $2m_\pi$ threshold

$\to$ 2008

Scalar, pseudoscalar : future plans

1) Submit 6 papers → 2007, early 2008

- $\eta \to \pi^+\pi^+ e^+ e^-$: BR and decay plane asymmetry (CP viol.)

  → prel. with 25% * stat. within 2007

- $\eta \to \pi^0\gamma\gamma$: BR and $M_{\gamma\gamma}$ spectrum (χPT)

  → update on whole stat. within 2008

- Combined fit for $f_0 - \sigma$ parameters using $\pi^0\pi^0\gamma$ and $\pi^+\pi^-\gamma$ final states

  → 2008

- $\eta' \to \eta\, \pi^+\pi^-$ Dalitz → to be started

$K_{\mu 3}$ - beyond quadratic parametrization

the Callan-Treiman relation fixes the value of $f_0(t) = \tilde{f}_0(t) f_+(0)$ at t=$\Delta_{K\pi}$= m_K^2-m_π^2

$$\tilde{f}_0(\Delta_{K\pi}) = \frac{f_K}{f_\pi}\frac{1}{f_+(0)} + \Delta_{CT}$$

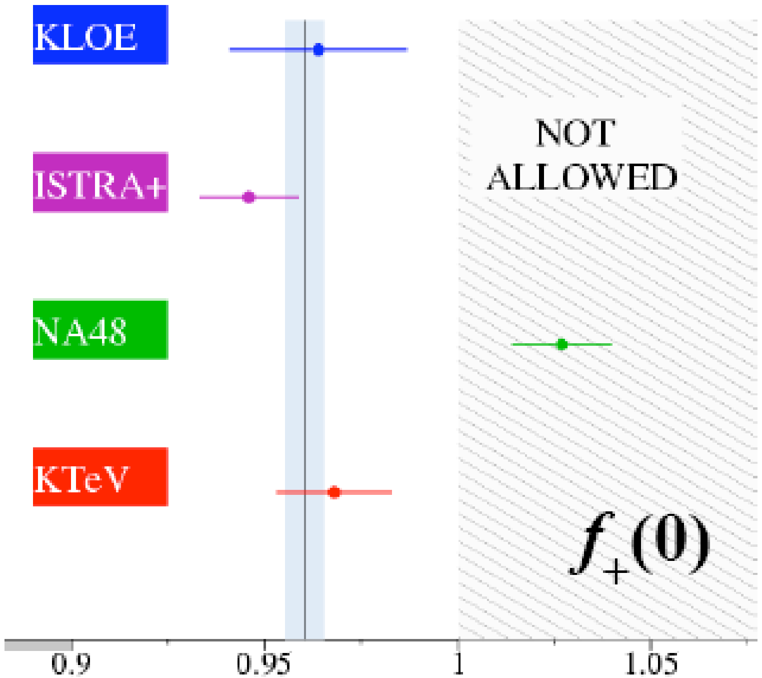
where Δ_{CT} = -3.5 x 10^{-3}

recent parametrization from Stern & coll. *(PLB638 -2006)* takes into account such constraint ➔ we evaluate $\tilde{f}_0(\Delta_{K\pi})$ fitting the Kμ3 data with the dispersive relation

$$f_0(t) = \exp\left[\frac{t}{m_K^2 - m_\pi^2}(\ln C - G(t))\right]$$

giving $\tilde{f}_0(\Delta_{K\pi}) = C$ = 1.23(3)

f+(0) = 0.961(5) RBC/UKQCD 07



f_K/f_π = 1.189(7) HP-UKQCD 07

KLOE value $f_+(0)$ = 0.964(23) in good agreement with lattice calculations

from Kμ3 and Ke3 data, we find

λ_+ = (25.7 ± 0.6) x 10^{-3}	$\rho(\lambda_+,\lambda_0)$ = -0.26
λ_0 = (14.0 ± 2.1) x 10^{-3}	χ^2/ndof = 2.6/3