Highlights from KLOE

Roberto Versaci *

on behalf of the KLOE collaboration

* Laboratori Nazionali di Frascati - INFN

Outline

- CKM and Vus
- KLOE and DAΦNE
- Neutral kaons
- Charged kaons
- Hadronic physics
- Future plans

CKM matrix and V_{us}

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Unitarity of the CKM matrix is a test of the Standard Model

The lack of unitarity is a hint of new physics

The most precise test comes from the 1st row:

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

V_{ud} from super-allowed nuclear β decays

→ V_{us} from kaon decays

V_{ub} from B meson decays $O(10^{-3})$

V_{us} and semileptonic decays

$$\Gamma(K \to \pi \ell \nu(\gamma)) = \frac{G^2 m_K^5}{768\pi^3} C_K^2 |V_{us}|^2 \, |f_+^{K\pi}(0)|^2 \, I_K^\ell \, S_{ew} \, \left[1 + \delta_{SU(2)} + \delta_{em}\right]$$

$BR(K \to \pi l \nu) / \tau_K$

Clebsh-Gordan isospin factor
$C_K = 1$ ($1/\sqrt{2}$) for K^0 ($K^\pm$)

$f^{K\pi}(t)$: $K \to \pi$ form factor
$t = (p_K - p_\pi)^2$

Phase-space integral

Short-distance ew correction
$\approx 1 + (2\alpha/\pi) \, ln \, (M_Z / M_K)$

isospin-breaking + long-distance e.m. corrections (≈ %)

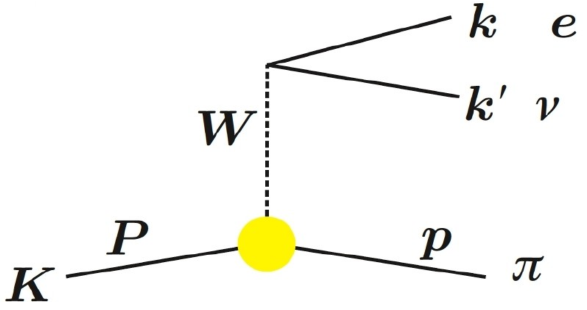
Experimental inputs:
- branching ratios
- K lifetime
- K mass
- form factor (t dependence)

Theoretical inputs:
- form factors at t=0
- phase-space integral
- SU(2), em, ew corrections

K_{l3} form factors

Hadronic matrix element:

$$\langle \pi | J_\alpha | K \rangle = f(0) \times [f_+(t)(P+p)_\alpha + f_-(t)(P-p)_\alpha]$$



f_- term only important for $K_{\mu 3}$

For $K_{\mu 3}$ use f_+ and $f_0(t) = f_+(t) + f_-(t) \times t / (m_K^2 - m_\pi^2)$

Form factor expansion: $f_+(t) = 1 + \lambda_+ [t/m_\pi^2]$

$f_+(t) = 1 + \lambda_+' [t/m_\pi^2] + ½ \lambda_+'' [t/m_\pi^2]^2$

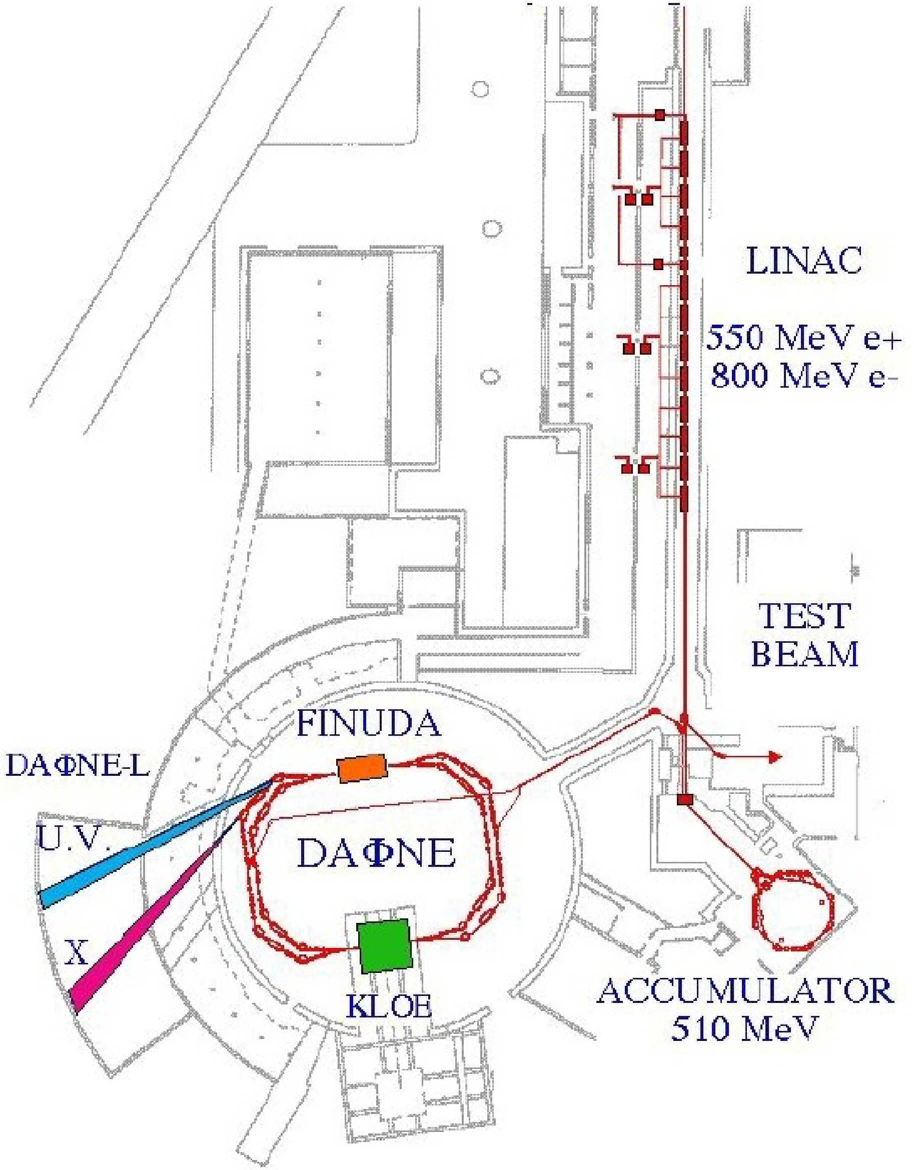
Polar expansion: $f_+(t) = \frac{M^2}{M^2 - t}$ $\lambda_+' = (m_\pi / M)^2$

$\lambda_+'' = 2\lambda_+'^2$

DAΦNE

Double **A**nnular ring

For **N**ice **E**xperiments



DAΦNE

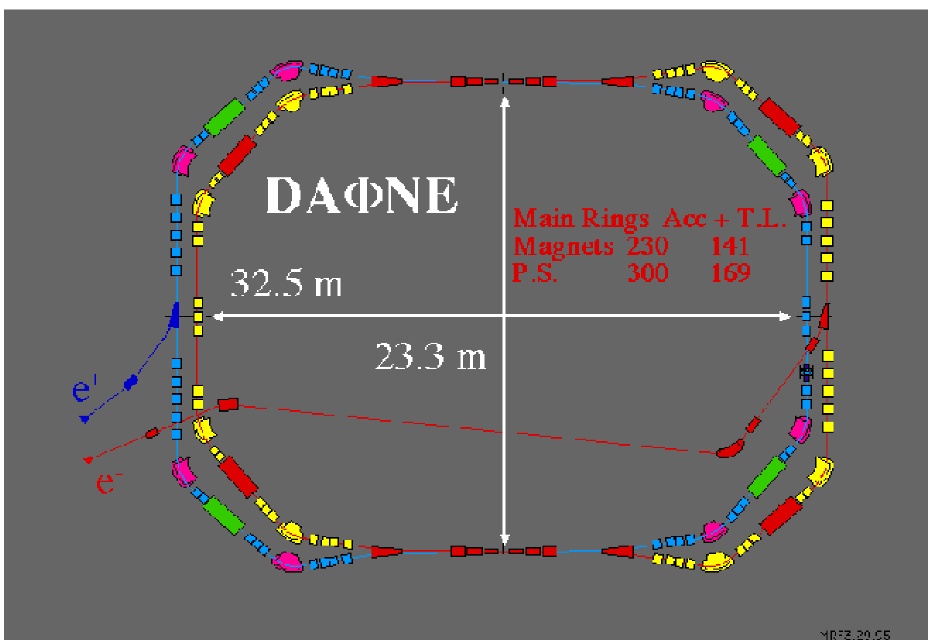
electron-positron collider

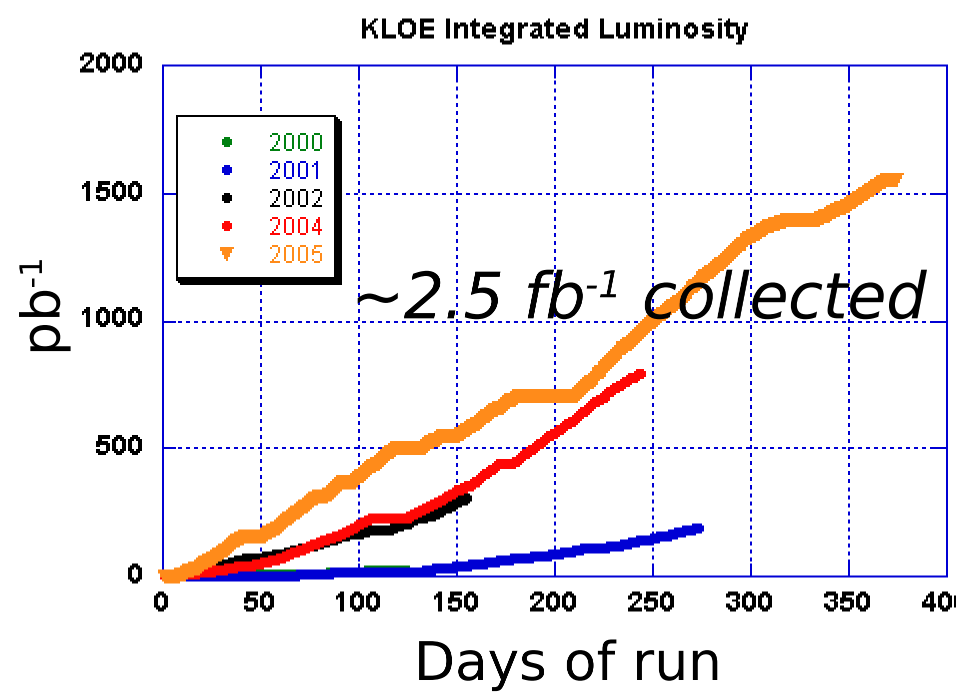
$\sqrt{s} = m_\phi = 1.019$ GeV $\sigma(\phi) \approx 3\ \mu b$

2 rings to minimize beam-beam interactions

12.5 mrad crossing angle

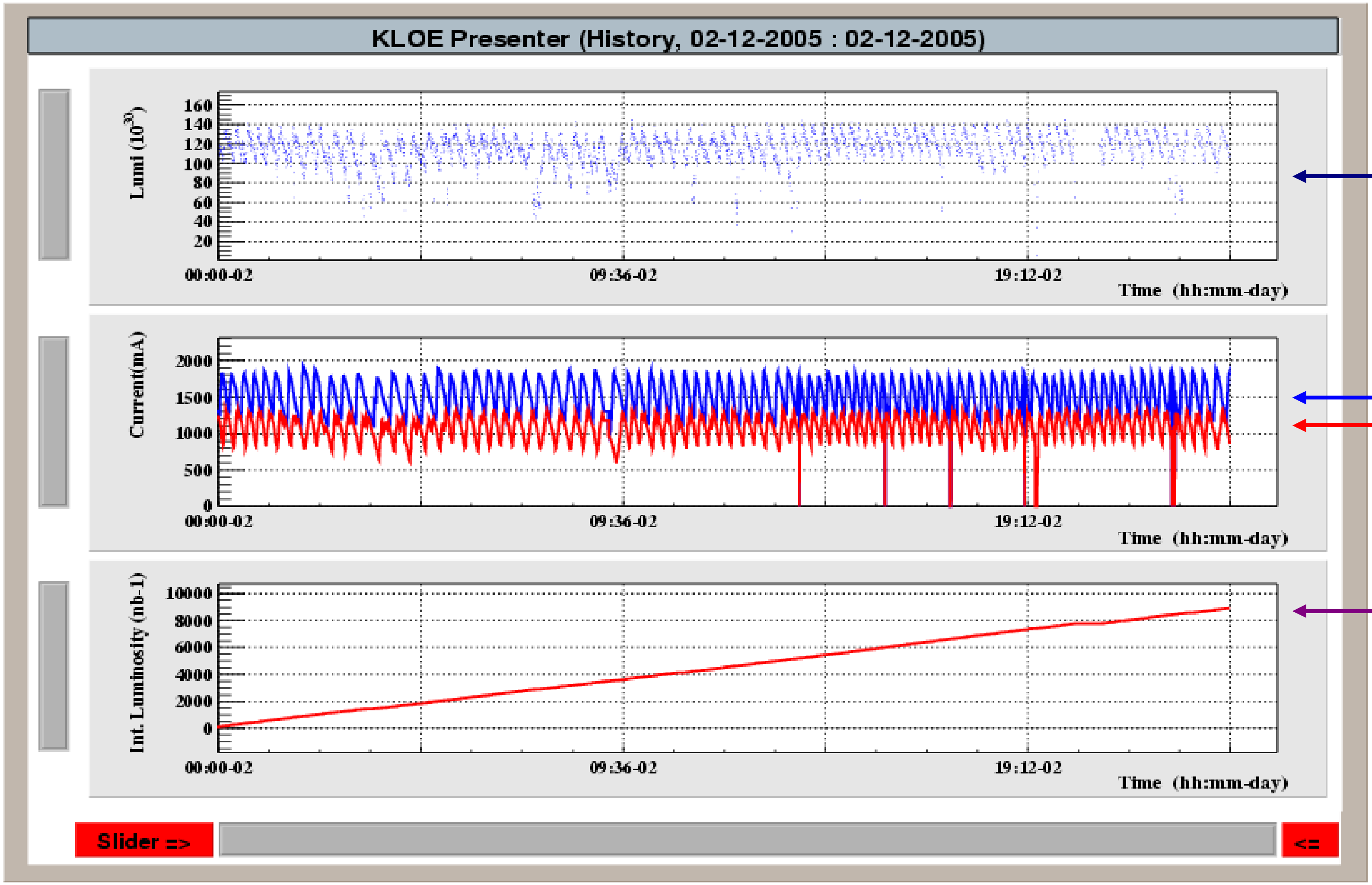
2 interaction regions (KLOE - DEAR/FINUDA)





DAΦNE

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



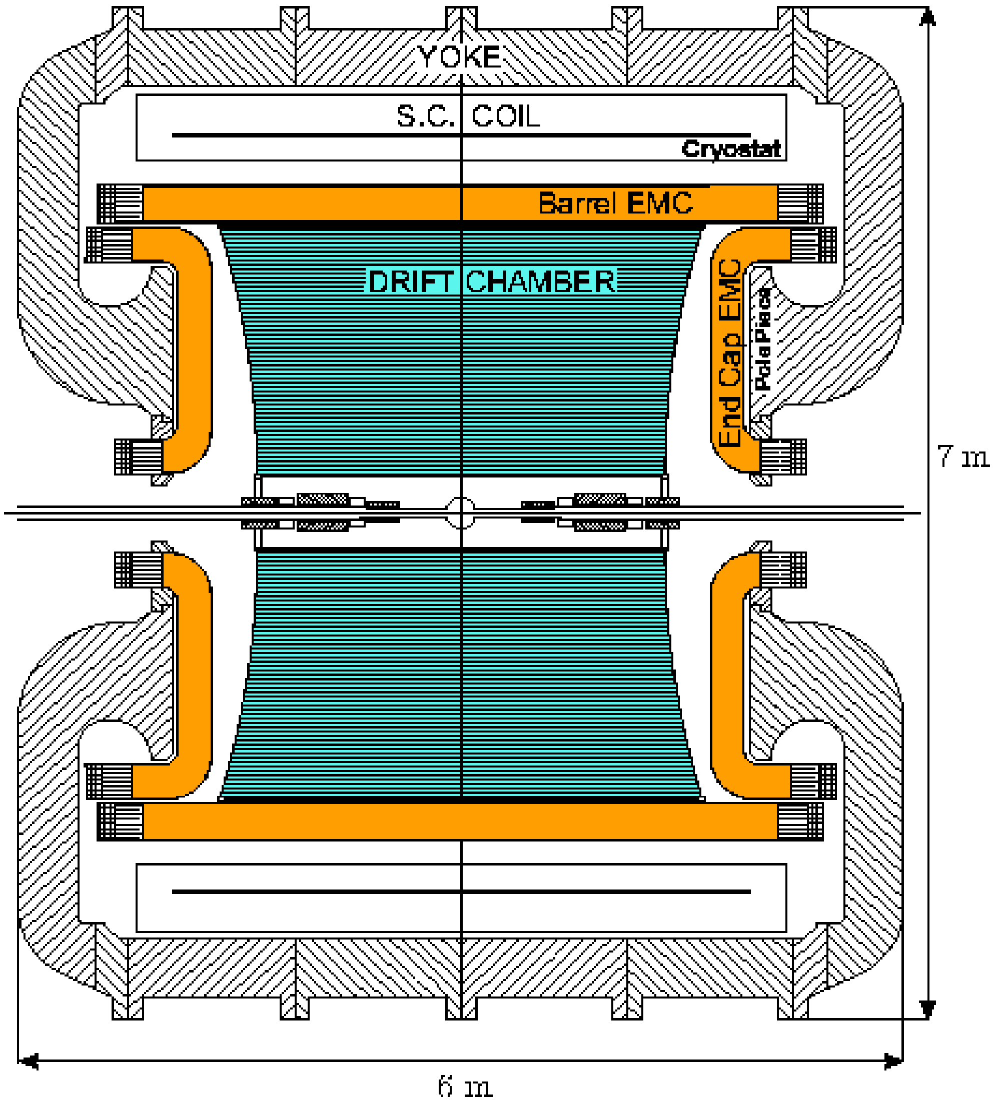
$L = 1.2 \cdot 10^{32}$ $cm^{-2}\ s^{-1}$

$I(e^-) = 1.6$ A

$I(e^+) = 1.1$ A

$\int Ldt = 8\ pb^{-1}$

K LOng Experiment



Spherical ***beam pipe***
10 cm Ø, 0.5 mm thick in Be-Al alloy
to minimize regeneration,
scattering and γ conversion

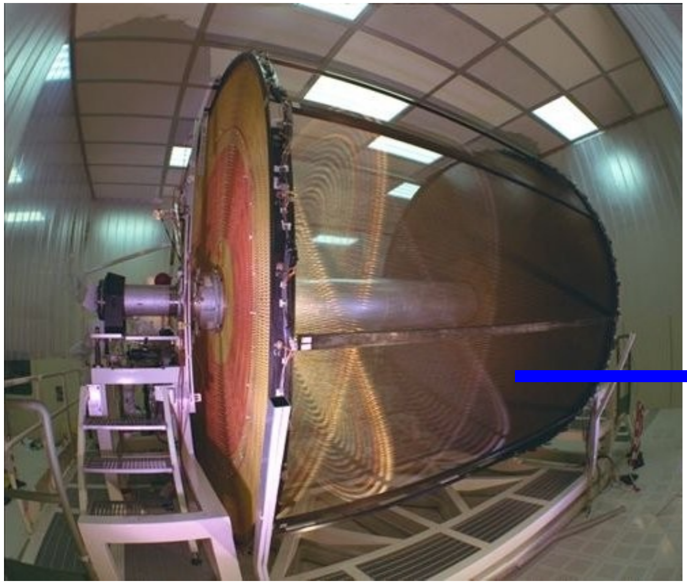
Large volume ***drift chamber***
4 cm Ø, L=3.4 m, carbon-fiber frame,
low density gas (90% He – 10% C_4H_{10}),
12582 all stereo squared cells,
tungsten and aluminium wires (52140)

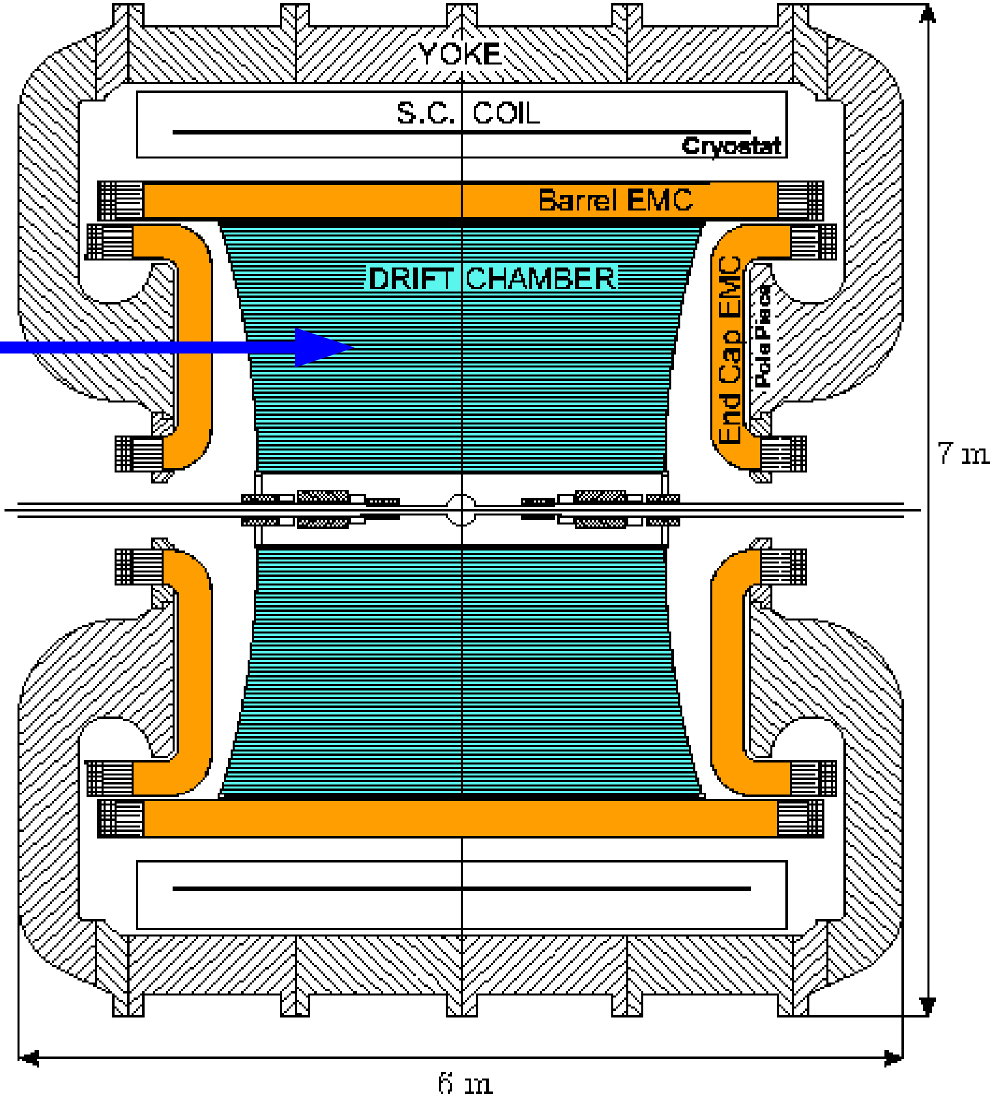
~4π ***calorimeter***, 4880 cells
$15X_0$ thick, 0.5 mm lead
1mmØ scintillating fibers

Superconducting coil B = 0.52 T

Remind: λ_L = 3.5m

KLOE - Drift Chamber





$\sigma_{r\phi} = 150\ \mu m$

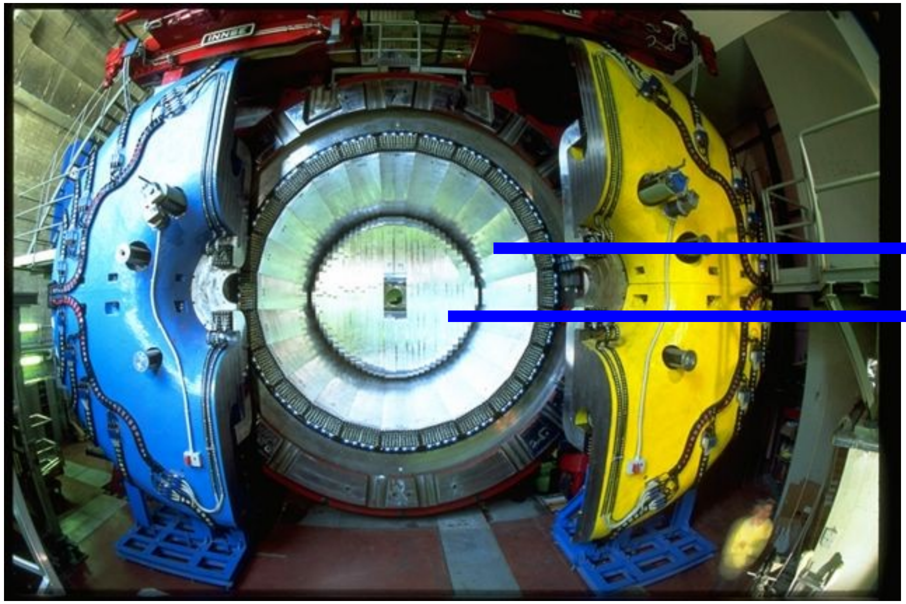
$\sigma_z = 2$ mm

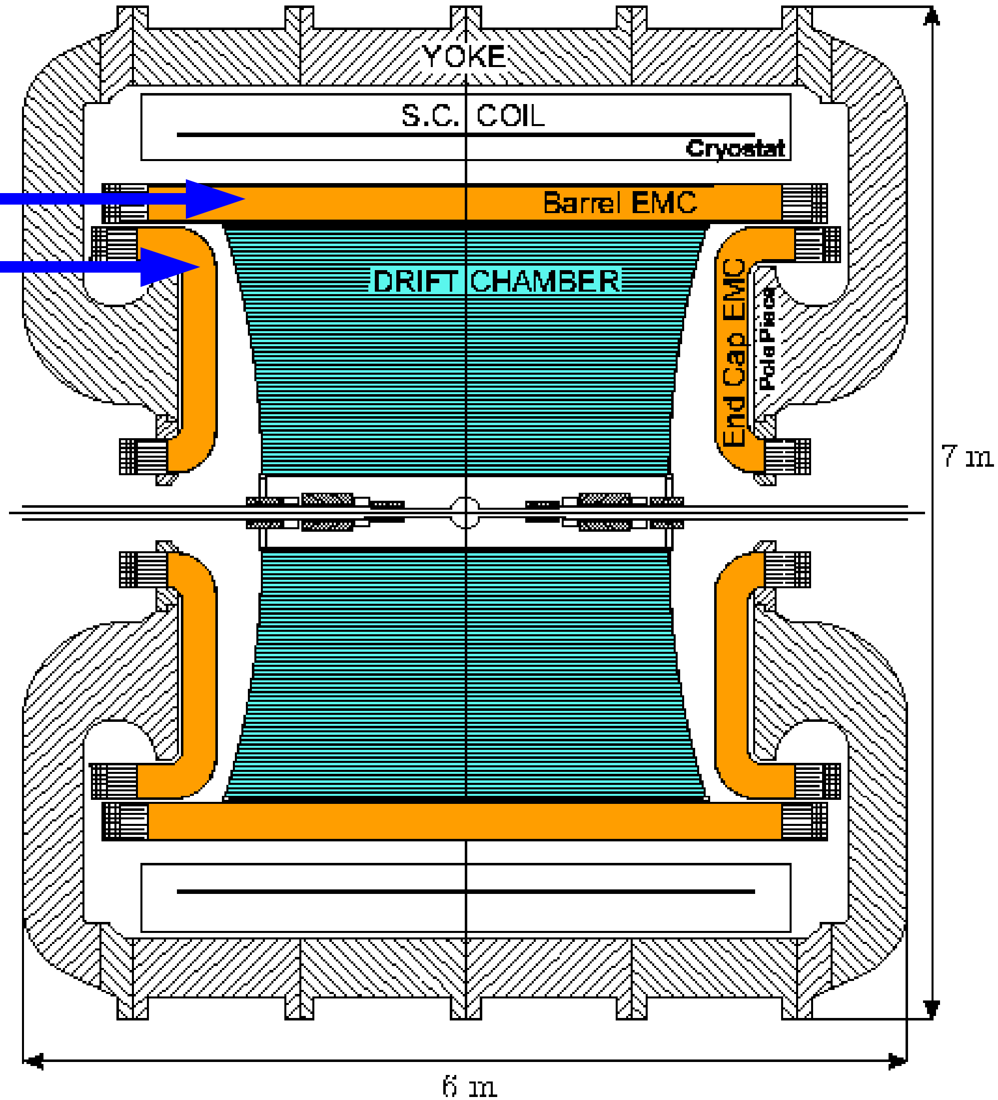
$\sigma_p/p \sim 4 \times 10^{-3}$

$\sigma_{vertex} \sim 3$ mm

$\sigma(m_{\pi\pi}) \sim 1$ MeV

KLOE - EM Calorimeter





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 ($K_L \rightarrow \pi^+\pi^-\pi^0$)

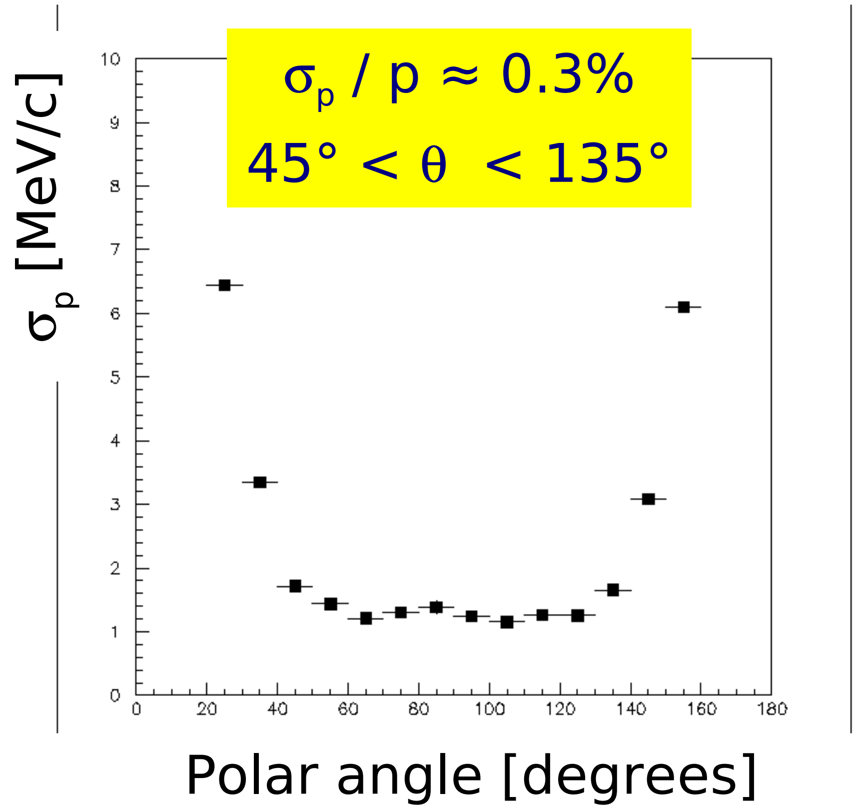
ε > 95% for E_γ > 20 MeV

π/e PID based on TOF

Tracking in the DC

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

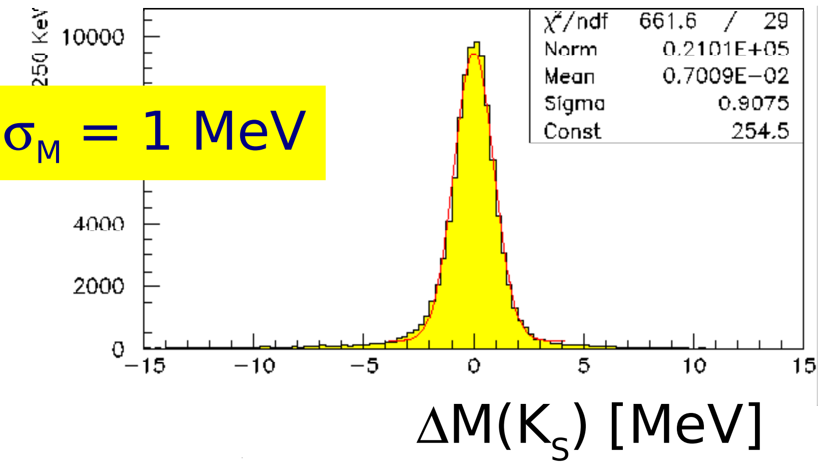
Bhabha scattering events



$\sigma_p / p \approx 0.3\%$

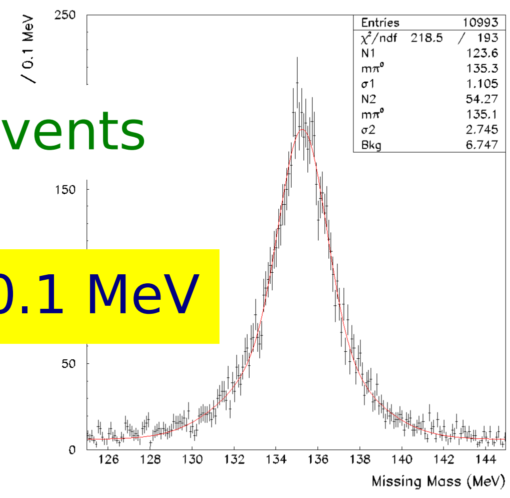
$45° < \theta < 135°$

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



σ_M = 1 MeV

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

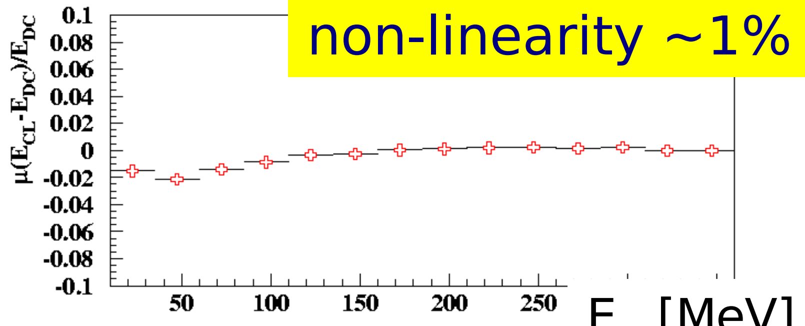


$M(\pi^0) = 135.3 \pm 0.1$ MeV

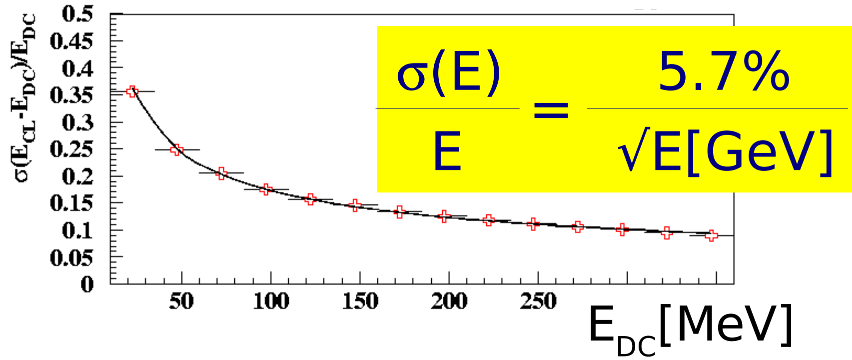
Measuring photons

Energy resolution

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

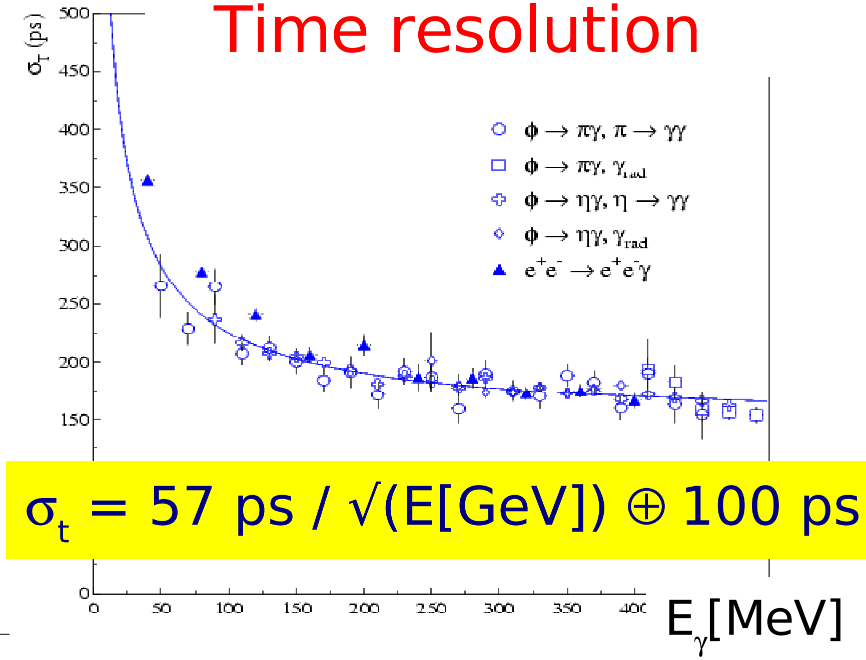


non-linearity ~1%



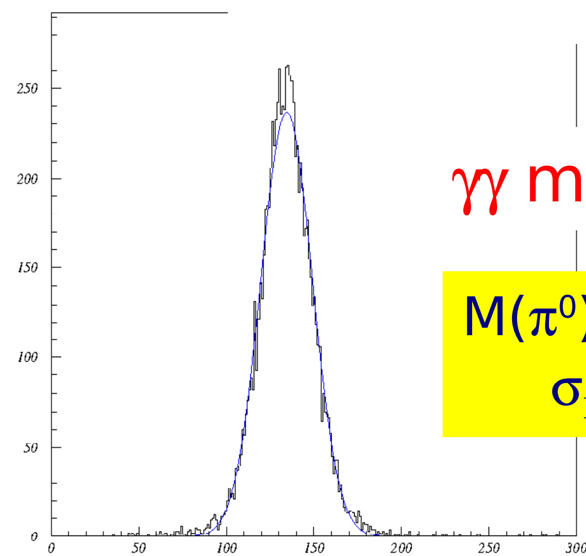
$$\frac{\sigma(E)}{E} = \frac{5.7\%}{\sqrt{E[\mathrm{GeV}]}}$$

Time resolution



σ_t = 57 ps / $\sqrt{(E[\mathrm{GeV}])}$ ⊕ 100 ps

γγ mass resolution



$M(\pi^0)$ = 134.5 MeV
$\sigma_M \approx$ 14 MeV

The trigger

bunch crossing period is 2.7 ns

L/c of prompt photon ≈ 7 ns, L/βc of K ≈ 30 ns

- Based on EMC energy deposit (≥2 isolated clusters) and DC multiplicity (≥15 cells within 250 ns)
- Bhabha veto (downscaled sample)
- Cosmic ray veto (rate 3kHz ; downscaled sample)
- 3rd level trigger (recover wrong CR vetoed events)

Typical data acquistion rate ≈ 2.5 kHz

- 1/2 machine background
- 1/4 cosmic rays
- 1/4 e^+e^- collisions

Tagging

The ϕ decay at rest provides monochromatic and pure kaon beams

The detection of a K guarantees the presence of the $\overline{K}$ with known momentum $\Rightarrow$ **Tag mechanism**

Normalization to the number of tags allows a precise measurement of absolute BRs

$K^\pm \rightarrow \mu\,\nu_\mu$ $K^\pm \rightarrow \pi\,\pi^0$	K^+K^- 1.5×10^6/pb^{-1} p* = 127 MeV/c $\lambda_\pm$ = 95 cm	K_LK_S 10^6/pb^{-1} p* = 110 MeV/c λ_S = 6 mm λ_L = 3.4 m	$K_S \rightarrow \pi^+\pi^-$ K_L interacts in EMC

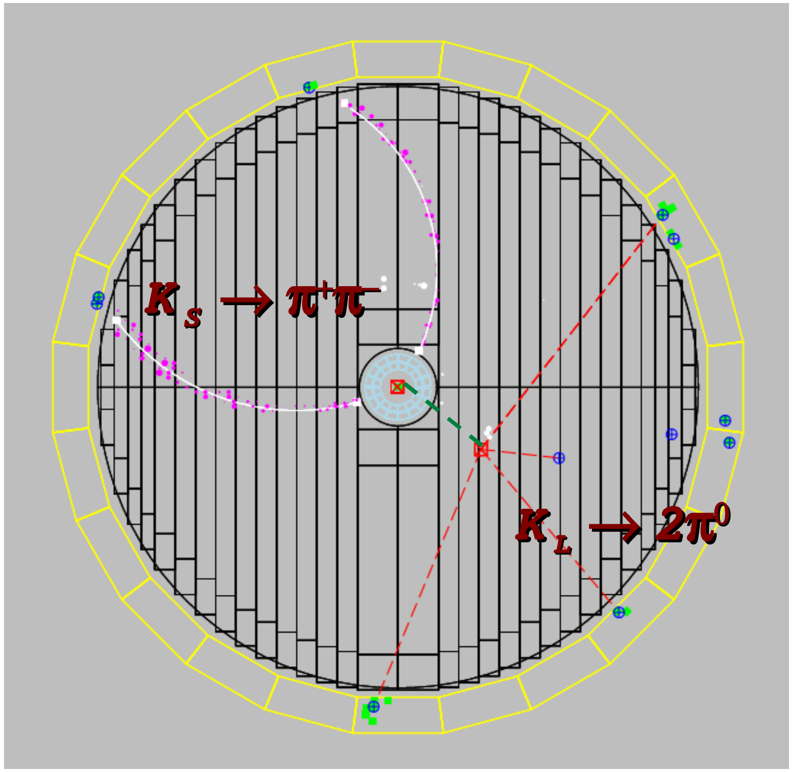
Neutral kaons

- Main K_L branching ratios
- K_L lifetime
- $K_L \to \pi e \nu_e$ form factor
- $K_L \to \pi^+ \pi^- (\gamma)$
- $K_S \to \pi^+ \pi^- (\gamma)$ / $K_S \to \pi^0 \pi^0$
- $K_S \to \pi e \nu_e$; A_S ; form factor
- $K_S \to \pi \mu \nu_e$
- $K_S \to \pi^0 \pi^0 \pi^0$
- QM, CP and CPT tests

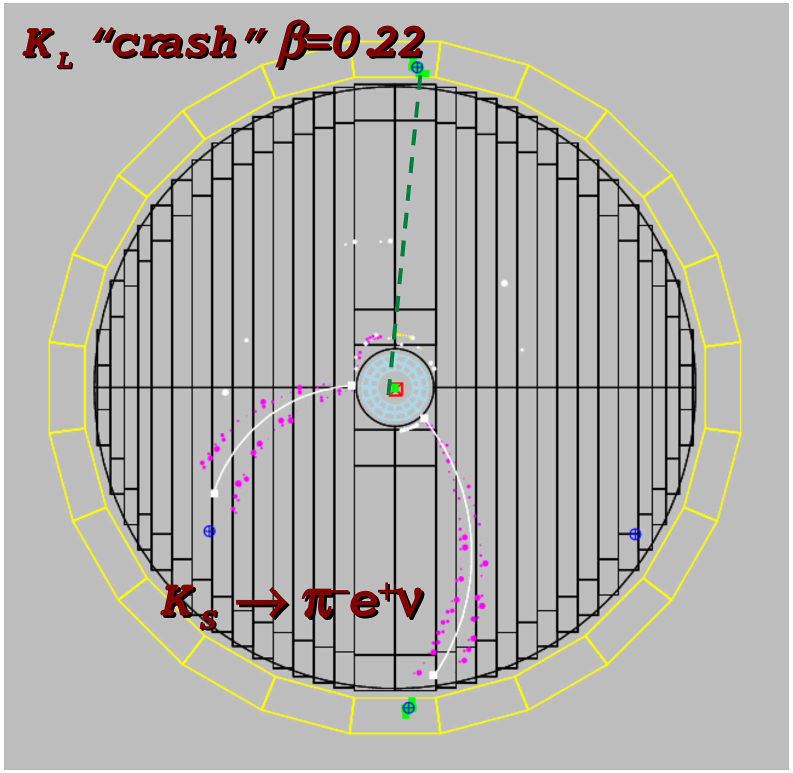
Data sample between 200 and 400 pb^{-1}

Tagging neutral kaons

K_L tagged by $K_S \to \pi^+\pi^-$



K_S tagged by K_L interaction



$\varepsilon \sim 70\%$ geom. & vertex

$\sigma_\theta(K_L) \sim 1°$; $\sigma_p(K_L) \sim 1$ MeV

$\varepsilon \sim 30\%$ geom. & energy cut

$\sigma_\theta(K_S) \sim 1°$; $\sigma_p(K_S) \sim 1$ MeV

K_L decays

PLB 632 (2006) 43

Main K_L BRs

$$BR(K_L \to f) = \frac{N_f}{N_{tag}} \cdot \frac{1}{\epsilon^f_{rec} \cdot \epsilon_{FV}(\tau_L) \cdot C_{TB}}$$

Tag from K_S

Tag bias correction: O(1%)

Reconstruction efficiency:

$K_L \to \pi e \nu, \pi \mu \nu$ $\varepsilon \approx 55\%$

$K_L \to \pi^+\pi^-\pi^0$ $\varepsilon \approx 40\%$

$K_L \to \pi^0\pi^0\pi^0$ $\varepsilon \approx 99\%$

Acceptance: $\varepsilon \approx 26\%$

328 pb^{-1} ~13×10^6 K_L events

¼ for the measurement

¾ for the efficiencies

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

- energy-clusters vertex reconstructed by TOF
- ε_{rec} = 99%, background < 1%

$\pi e \nu, \pi \mu \nu, \pi^+\pi^-\pi^0$

- two-tracks vertex in the fiducial volume
- PID using shower shape, TOF and decay kinematics
- best discriminating variable: lesser of p_{miss}-E_{miss} in π–μ or μ–π hypothesis
- fit the MonteCarlo distribution including radiative processes

PLB 632 (2006) 43

Main K_L BRs

Error dominated by error in τ_L, needed for geometrical acceptance

328pb^{-1} from
2001-2002 data

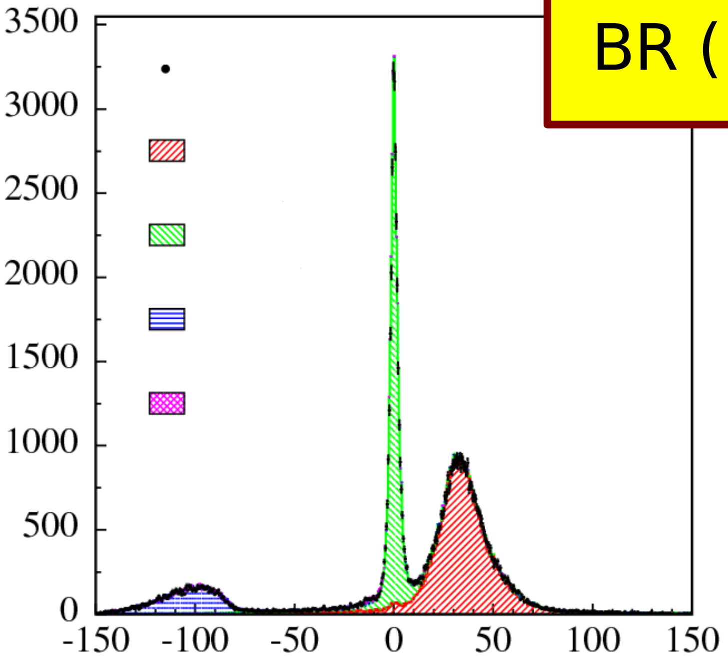
$BR(K_L \to \pi e \nu_e) = 0.4049 \pm 0.0010 \pm 0.0030$

$BR(K_L \to \pi \mu \nu_\mu) = 0.2726 \pm 0.0008 \pm 0.0022$

$BR(K_L \to \pi^0\pi^0\pi^0) = 0.2018 \pm 0.0005 \pm 0.0026$

$BR(K_L \to \pi^+\pi^-\pi^0) = 0.1276 \pm 0.0006 \pm 0.0016$

$\Delta_{\mu\pi}$ = lesser of p_{miss}-E_{miss} in π–μ or μ–π hypothesis



$\Delta_{\mu\pi}$[MeV]

$BR(\pi e \nu + \pi \mu \nu + \pi^+\pi^-\pi^0 + \pi^0\pi^0\pi^0)$ from KLOE +

$BR(\pi^+\pi^- + \pi^0\pi^0 + \gamma\gamma)$ from PDG'04

$= 1.0104 \pm 0.0076$

~ 0.36 %

PLB 632 (2006) 43

Main K_L BRs

Normalize Σ_x BR($K_L \rightarrow$ x) = 1 and solve for τ_L
taking KLOE BRs & BR($\pi^+\pi^- + \pi^0\pi^0 + \gamma\gamma$) from PDG'04

BR ($K_L \rightarrow \pi e \nu_e$) = 0.4007 ± 0.0006 ± 0.0014	800k evts
BR ($K_L \rightarrow \pi \mu \nu_\mu$) = 0.2698 ± 0.0006 ± 0.0014	500k evts
BR ($K_L \rightarrow \pi^0\pi^0\pi^0$) = 0.1997 ± 0.0005 ± 0.0019	700k evts
BR ($K_L \rightarrow \pi^+\pi^-\pi^0$) = 0.1263 ± 0.0005 ± 0.0011	200k evts

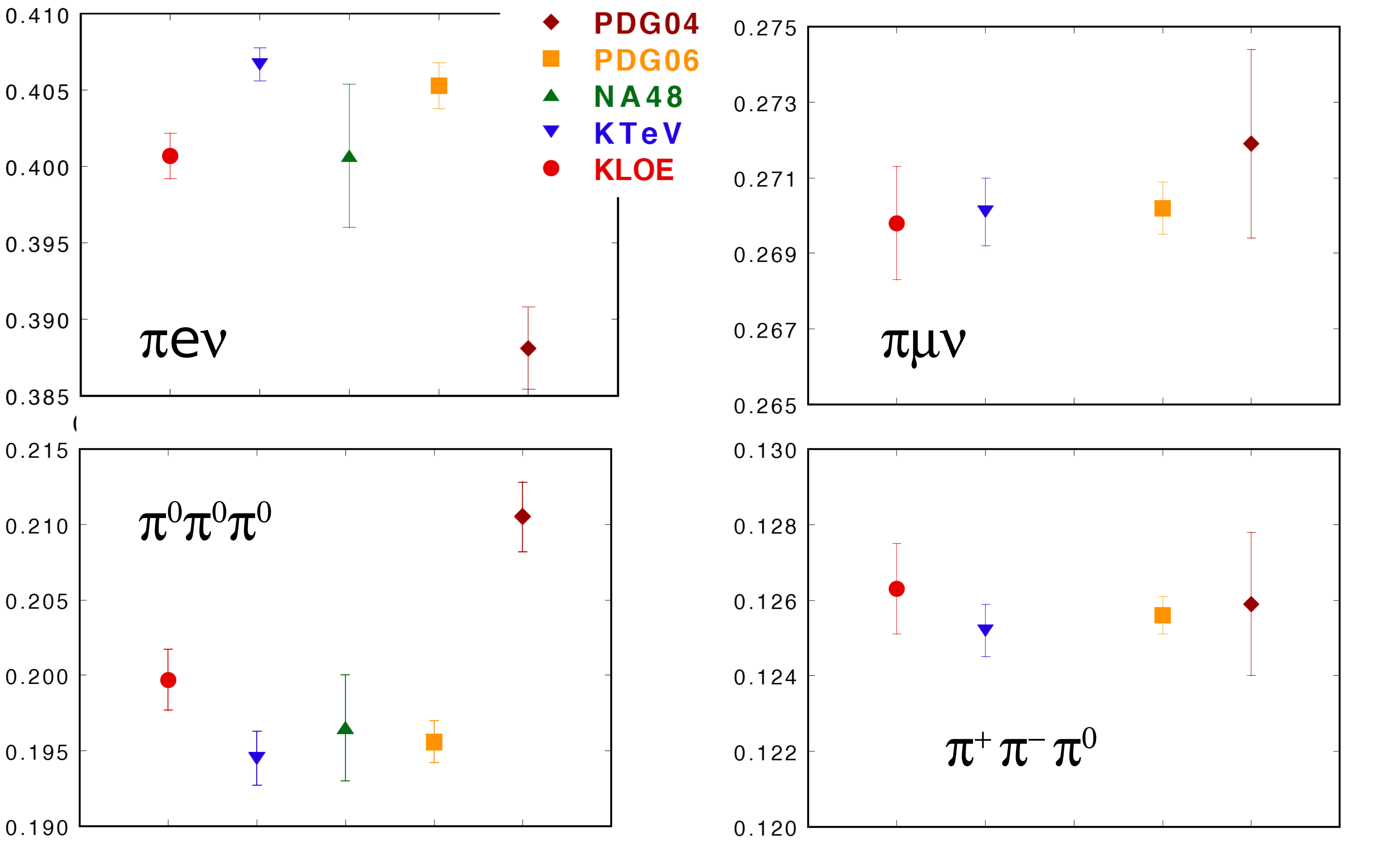
τ_L = (50.72 ± 0.17 ± 0.33) ns

Average with KLOE direct measurement **PLB 626 (2005) 15** :

τ_L = (50.84 ± 0.23) ns

PLB 632 (2006) 43

Main K_L BRs



PLB 626 (2005) 15

K_L lifetime

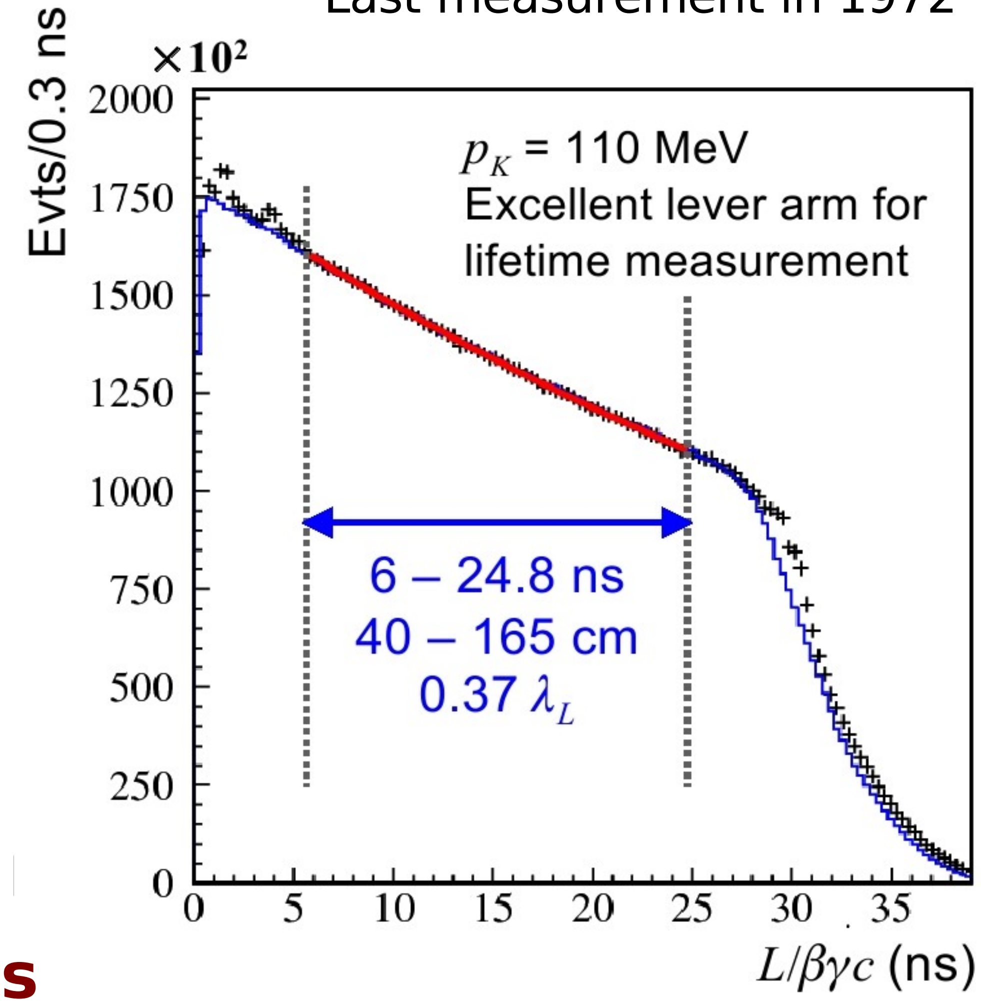
100M $K_L \to \pi^0\pi^0\pi^0$ events

- Require ≥ 3 γ s
- $\varepsilon(L_K)$ ~99%, uniform in L
- Background ~1.3%

Use $K_L \to \pi^+\pi^-\pi^0$ to determine

- Calorimeter timescale
- Photon-vertex efficiency
- Resolution: $\sigma_L(\gamma\gamma)$ ~ 2 cm

Last measurement in 1972



Direct measurement:

τ_L **= (50.92 ± 0.17 ± 0.25) ns**

Average with result from K_L BRs: τ_L **= (50.84 ± 0.23) ns**

$K_L \to \pi e \nu_e$ form factor

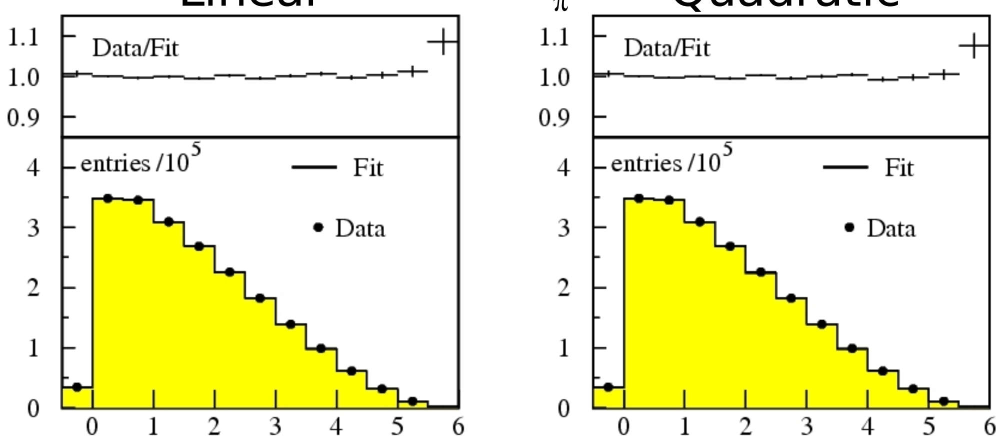
Form factor expansion:

PLB 636 (2006) 166

- linear $f_+(t) = 1 + \lambda_+ \, [t/m_\pi^2]$
- quadratic $f_+(t) = 1 + \lambda_+' \, [t/m_\pi^2] + ½ \, \lambda_+'' \, [t/m_\pi^2]^2$

Linear	Quadratic
$\lambda_+ = (28.6 \pm 0.5 \pm 0.4) \times 10^{-3}$	$\lambda_+' = (25.5 \pm 1.5 \pm 1.0) \times 10^{-3}$ $\lambda_+'' = (1.4 \pm 0.7 \pm 0.4) \times 10^{-3}$
χ^2 / dof = 330 / 363 $P(\chi^2)$ = 0.89	χ^2 / dof = 325 / 362 $P(\chi^2)$ = 0.92

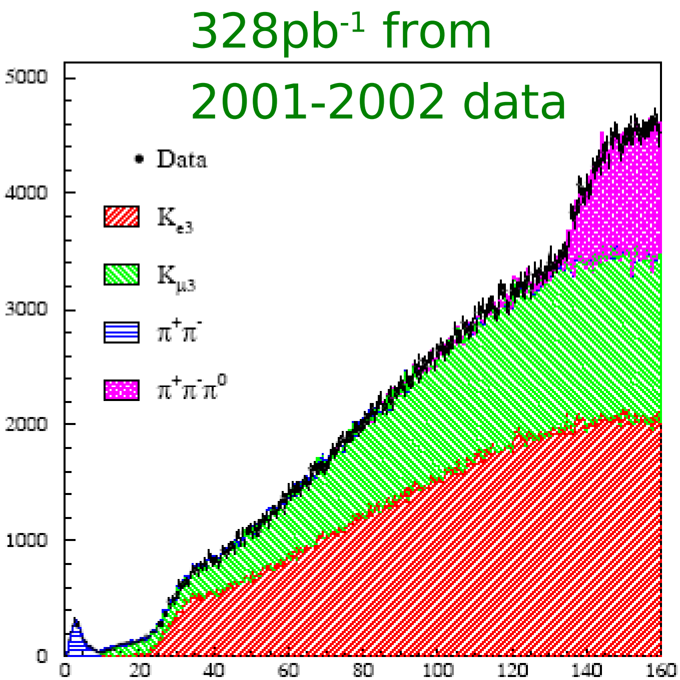
Linear t/m_π^2 Quadratic

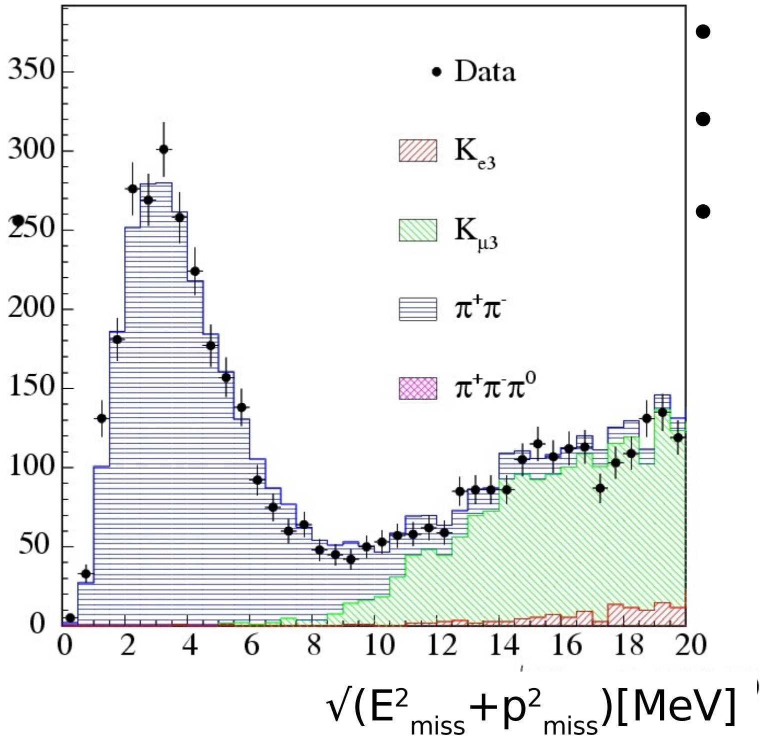


one pole parametrization: $\dfrac{M_V^2}{M_V^2 - t}$

$M_V = (870 \pm 6 \pm 7)$ MeV

$P(\chi^2) = 0.924$





$K_L \to \pi^+\pi^-(\gamma)$

PLB 638 (2006) 140

- Measurement of the ratio

  $BR(K_L \to \pi^+\pi^-) / BR(K_L \to \pi\mu\nu_\mu)$
- Select all K_L decays
- $\sqrt{(E^2_{miss}+p^2_{miss})}$ best discriminating variable

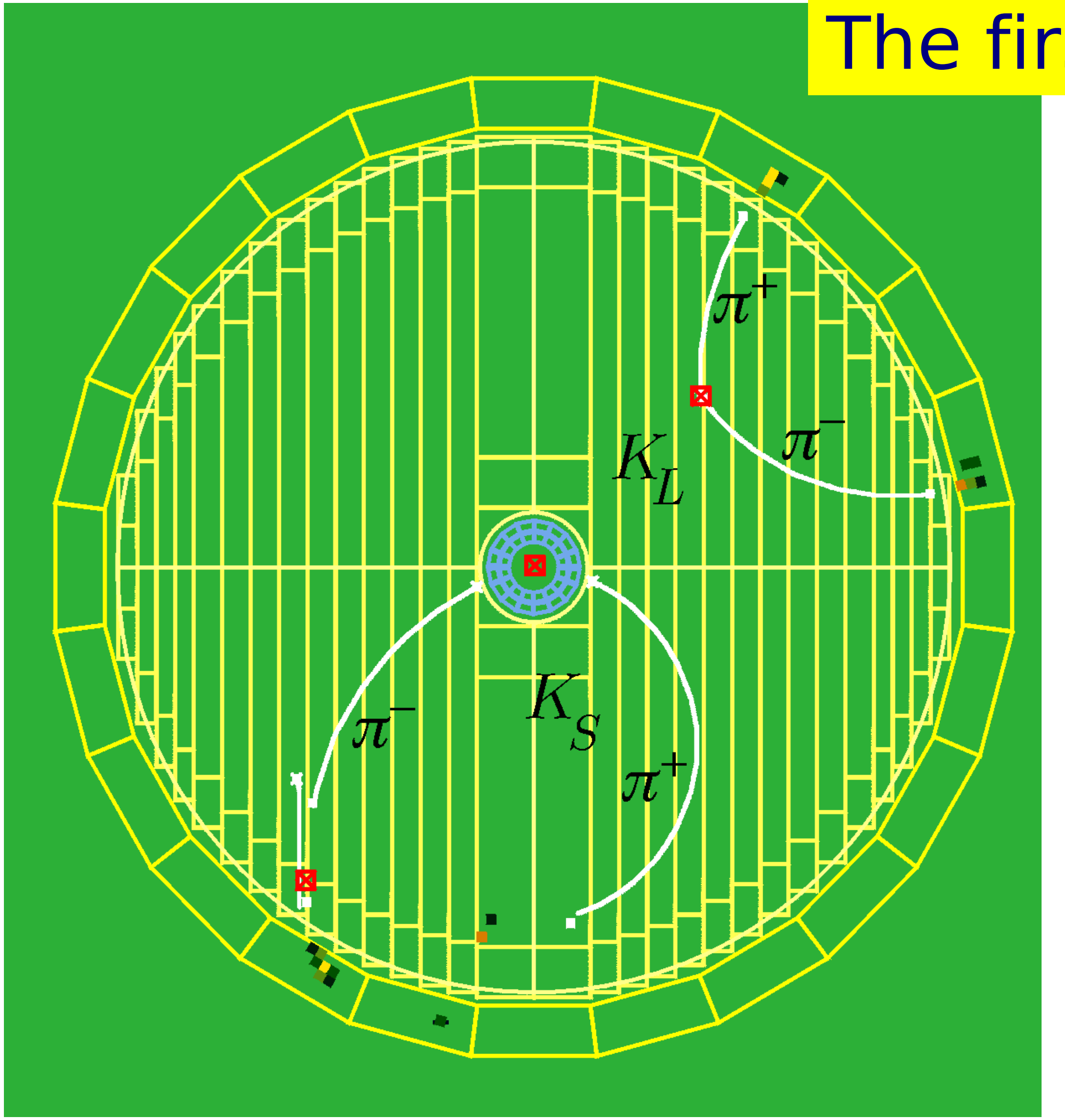
  for $K_L \to \pi^+\pi^-$
- Fit the distribution with MC shapes
- $BR(K_L \to \pi\mu\nu_\mu)$ taken from KLOE measurement
- Normalize to the decay $K_L \to \pi\mu\nu$

  reduces systematics due to tag bias

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

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

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



The first CP violating event!

during DAΦNE
commissioning1999

K_S decays

$BR(K_S \to \pi^+\pi^-(\gamma))/BR(K_S \to \pi^0\pi^0)$

$K_S \to \pi^+\pi^-(\gamma)$:

- 2 tracks from the IP
- opposite curvature
- vertex
- $120 < p < 300$ MeV/c
- $30° < \theta < 150°$

$K_S \to \pi^0\pi^0$:

- 4 photons from the IP
- $E > 20$ MeV
- $25° < \theta < 155°$
- $| t - r/c | < 5\sigma_t$

Data sample: 410 pb^{-1}

Hep-ex/0601025 EPJC in press

$BR(K_S \to \pi^+\pi^-(\gamma))/BR(K_S \to \pi^0\pi^0)$

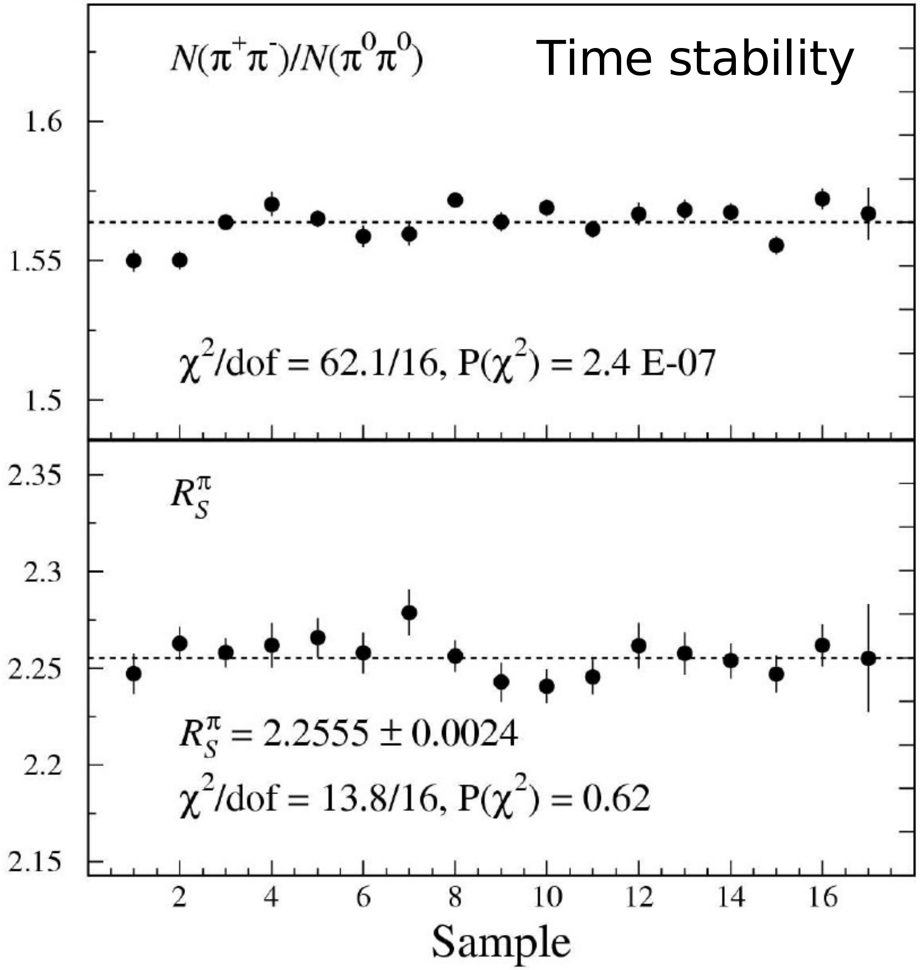
Hep-ex/0601025 EPJC in press

$R^{\pi}_{S} = 2.2555 \pm 0.0056$

Averaged with KLOE '02
Common syst. accounted for

$R^{\pi}_{S} = 2.2549 \pm 0.0054$

Most precise values



$BR(K_S \to \pi^+\pi^-(\gamma)) = (\ 69.196 \pm 0.051\ ) \times 10^{-2}$

$BR(K_S \to \pi^0\pi^0) = (\ 30.687 \pm 0.051\ ) \times 10^{-2}$

$K_S \to \pi e \nu_e (\gamma)$

- two tracks with opposite curvature
- that form a vertex close to the interaction region
- $M_{\pi\pi}$ < 490 MeV assigning the π mass
- e-π identification by time-of-flight
- fit the distribution of $E_{miss}(\pi e) - p_{miss}$

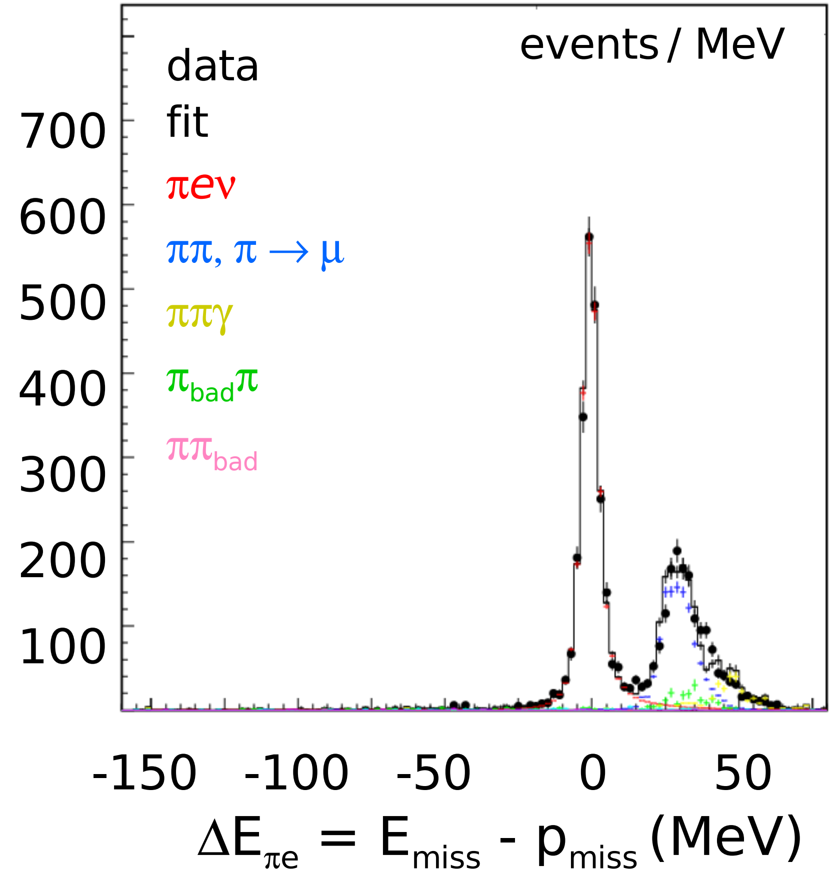
normalization to $K_S \to \pi^+\pi^-(\gamma)$

$BR(K_S \to \pi e \nu_e) = (7.082 \pm 0.092) \times 10^{-4}$

Linear slope of the form factor

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

Data sample: 410 pb^{-1}



PLB 636 (2006) 173

$K_S \rightarrow \pi e \nu_e (\gamma)$

Allows test of CP, CPT and ΔS = ΔQ rule

$$BR(K_S \rightarrow \pi^- e^+ \nu_e) = (3.528 \pm 0.062) \times 10^{-4}$$

$$BR(K_S \rightarrow \pi^+ e^- \nu_e) = (3.517 \pm 0.058) \times 10^{-4}$$

$$A_S = \frac{\Gamma(K_S \rightarrow \pi^- e^+ \nu_e) - \Gamma(K_S \rightarrow \pi^+ e^- \nu_e)}{\Gamma(K_S \rightarrow \pi^- e^+ \nu_e) + \Gamma(K_S \rightarrow \pi^+ e^- \nu_e)} = (1.5 \pm 9.6 \pm 2.9) \times 10^{-3}$$

Γ_S vs Γ_L: test of $\Delta S = \Delta Q$ rule

A_S vs A_L: tests of CP and CPT

With full statistics (5x)

A_S to 3×10^{-3}

$$A_S - A_L = 4\,(\text{Re}\,\delta + \text{Re}\,x_-)$$

$$A_S + A_L = 4\,(\text{Re}\,\varepsilon - \text{Re}\,y)$$

$$2\,\text{Re}\,x_+ = (\Gamma_S - \Gamma_L) / (\Gamma_S + \Gamma_L)$$

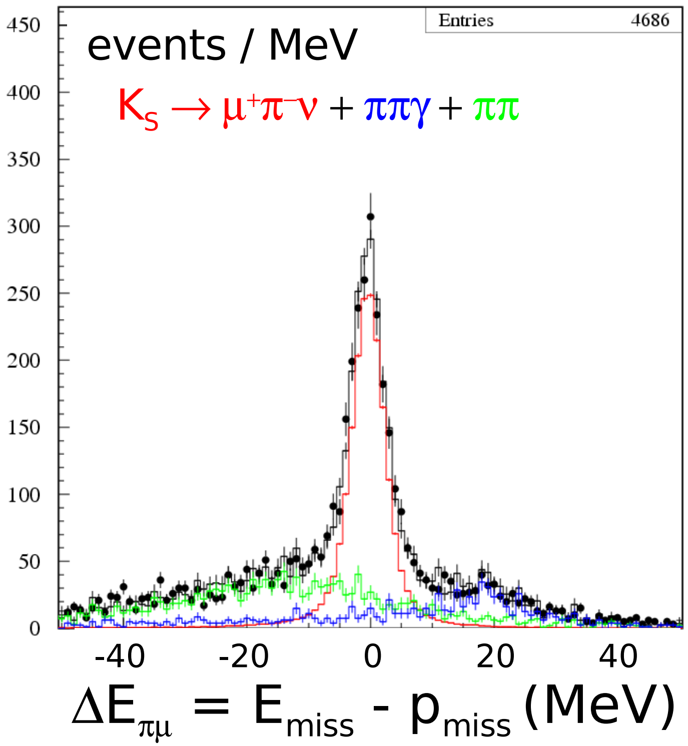
$\text{Re}\,x_+ = (-1.2 \pm 3.6) \times 10^{-3}$

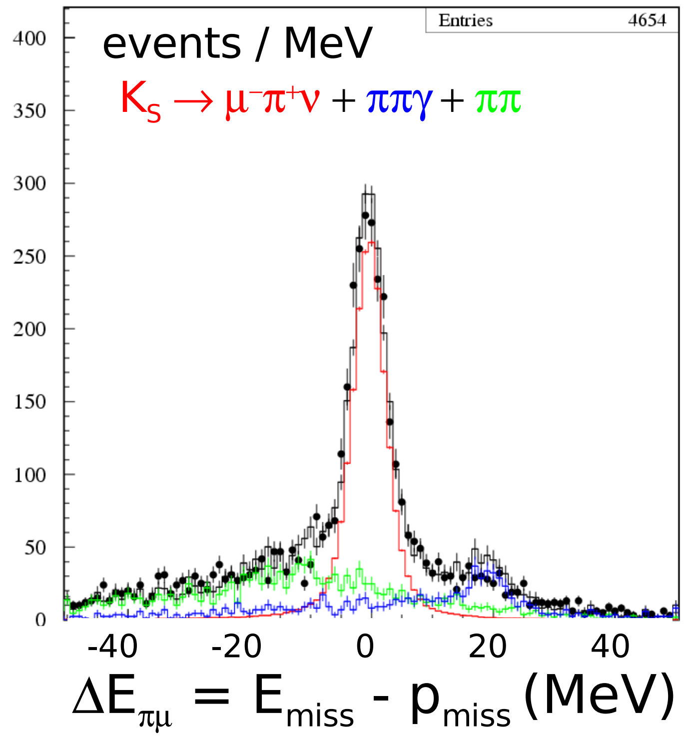
$\text{Re}\,x_- = (-0.8 \pm 2.5) \times 10^{-3}$

$\text{Re}\,y = (0.4 \pm 2.5) \times 10^{-3}$

$K_S \to \pi \mu \nu_\mu (\gamma)$

- two tracks with opposite curvature
- that form a vertex close to the interaction region
- $\mu - \pi$ identification by time-of-flight
- fit the distribution of $E_{miss}(\pi\mu)$ - p_{miss}





work in progress
should reach ≈ 3% statistical error with 410 pb^{-1}

PLB 619 (2005) 61

$K_S \to \pi^0 \pi^0 \pi^0$

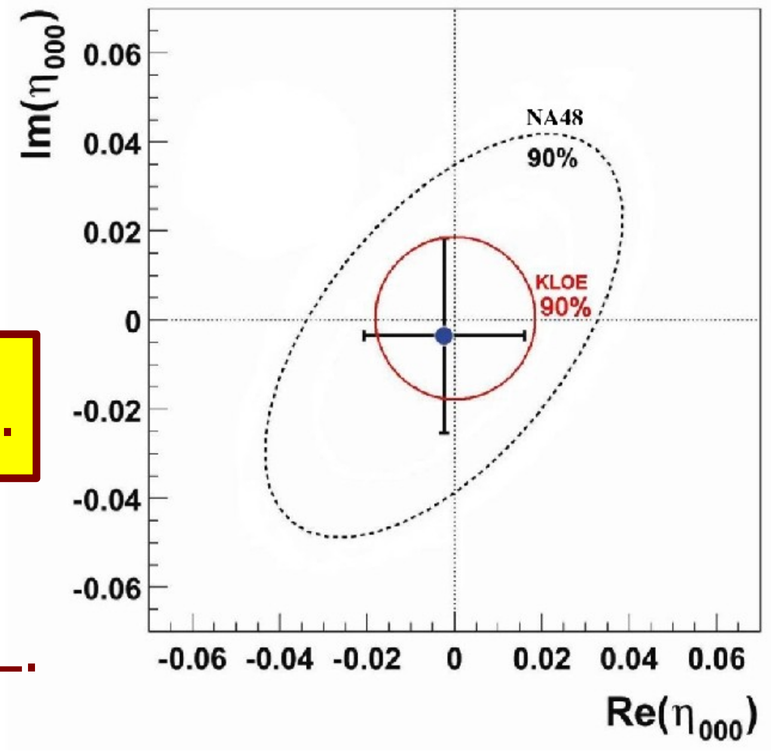
- K_L crash and 6 photons
- Kinematic fit
- Reject events with tracks from the IP
- Cuts using 4 vs 6 photons pairing
- Main background source:

  $K_S \to \pi^0\pi^0$ + 2 fake clusters
- Normalization to $K_S \to \pi^0\pi^0$

CP violation

$BR(K_S \to \pi^0\pi^0\pi^0) < 1.2 \times 10^{-7}$ 90% C.L.

$$|\eta_{000}| = \left|\frac{A(K_S \to 3\pi^0)}{A(K_L \to 3\pi^0)}\right| < 0.018 \quad 90\% \text{ C.L.}$$



QM, CP and CPT tests

To be published
PLB 642 (2006) 315

QM and CPT tests

Using quantum interference in $\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-\pi^+\pi^-$

$$I(t1,t2,\zeta) \propto \exp(-\Gamma_L t_1 - \Gamma_S t_1) + \exp(-\Gamma_S t_1 - \Gamma_L t_2)$$
$$- 2\boxed{(1-\zeta)} \exp(-(\Gamma_S + \Gamma_L)(t_1 + t_2)) \,/\, 2\cos(\Delta m \Delta t)$$

Decoherence parameter depends on the basis: ζ_{00}, ζ_{SL}

Loss of coherence $\zeta \neq 0 \Rightarrow$ ~~QM~~

Quantum gravity may result in ~~QM~~ and ~~CPT~~ (effect in $K^0\overline{K^0}$)

$I(t_1,t_2,\gamma)$ $\qquad \gamma \sim O(m_K^2/M_P) \neq 0$

$I(t_1,t_2,\omega)$ $\qquad \omega = |\omega| e^{i\Omega} \neq 0$

To be published
PLB 642 (2006) 315

QM and CPT tests

$\zeta_{SL} = 0.018 \pm 0.040 \pm 0.007$ χ^2/dof = 29.7/32

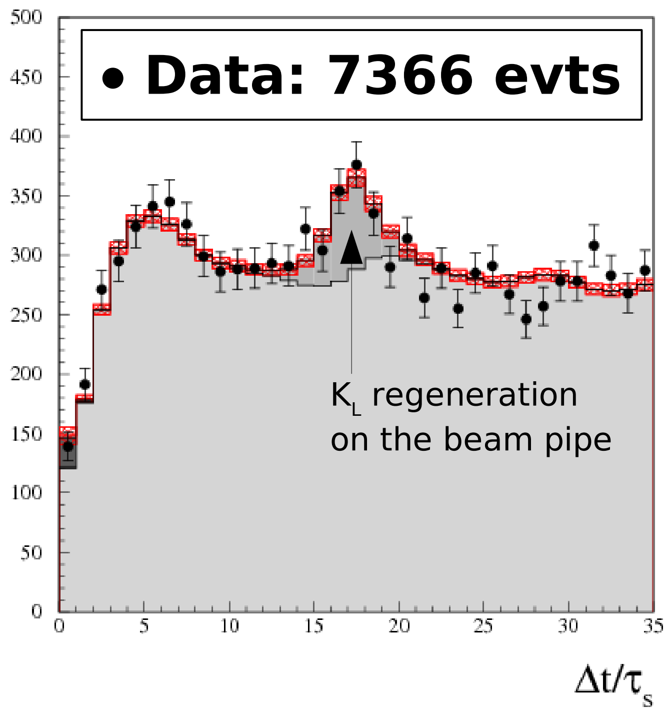
$\zeta_{00} = (0.10 \pm 0.21 \pm 0.04) \times 10^{-5}$ χ^2/dof = 29.6/32

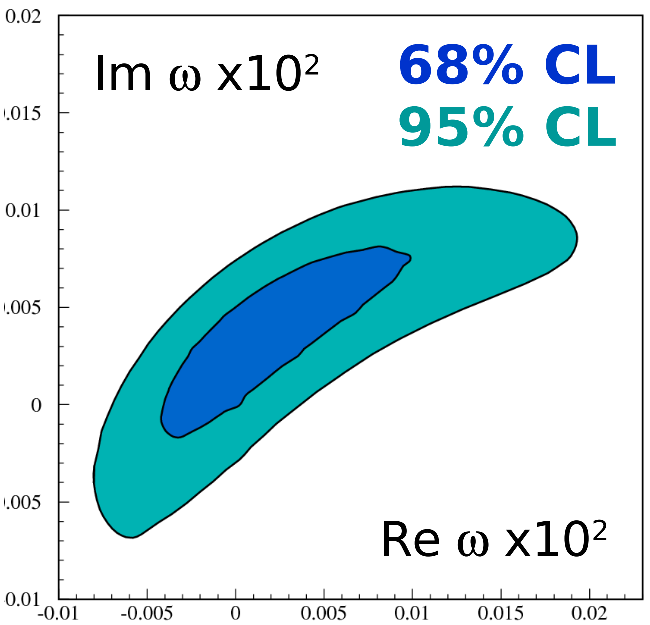
$\gamma = (1.3^{+2.8}_{-2.4} \pm 0.4) \times 10^{-21}$ GeV χ^2/dof = 33/32

$\Re\omega = (1.1^{+8.7}_{-5.3} \pm 0.9) \times 10^{-4}$ χ^2/dof = 29/31

$\Im\omega = (3.4^{+4.8}_{-5.0} \pm 0.6) \times 10^{-4}$

No evidence for ~~QM~~ and ~~CPT~~





Bell-Steinberger relation

CPT test in the kaons system
Assumes the unitarity
(i.e. probability conservation)

$$\tan\phi_{SW} = \frac{2(m_L - m_S)}{\Gamma_S - \Gamma_L}$$

$$\left[\frac{\Gamma_S+\Gamma_L}{\Gamma_S-\Gamma_L} + i\tan(\phi_{SW})\right]\frac{\Re(\epsilon) - i\Im(\delta)}{1+|\epsilon^2|} = \frac{1}{\Gamma_S-\Gamma_L}\sum A_L(f)A_S^*(f)$$

δ parametrize CPT violation

$$\delta = \frac{i(m_{K^0} - m_{\bar{K}^0}) + \frac{1}{2}(\Gamma_{K^0} - \Gamma_{\bar{K}^0})}{\Gamma_S - \Gamma_L}\cos\phi_{SW}\, e^{i\phi_{SW}}[1+O(\epsilon)]$$

δ can be used to constrain Δm_{K0} and $\Delta\Gamma$

JHEP12 (2006) 011
in press

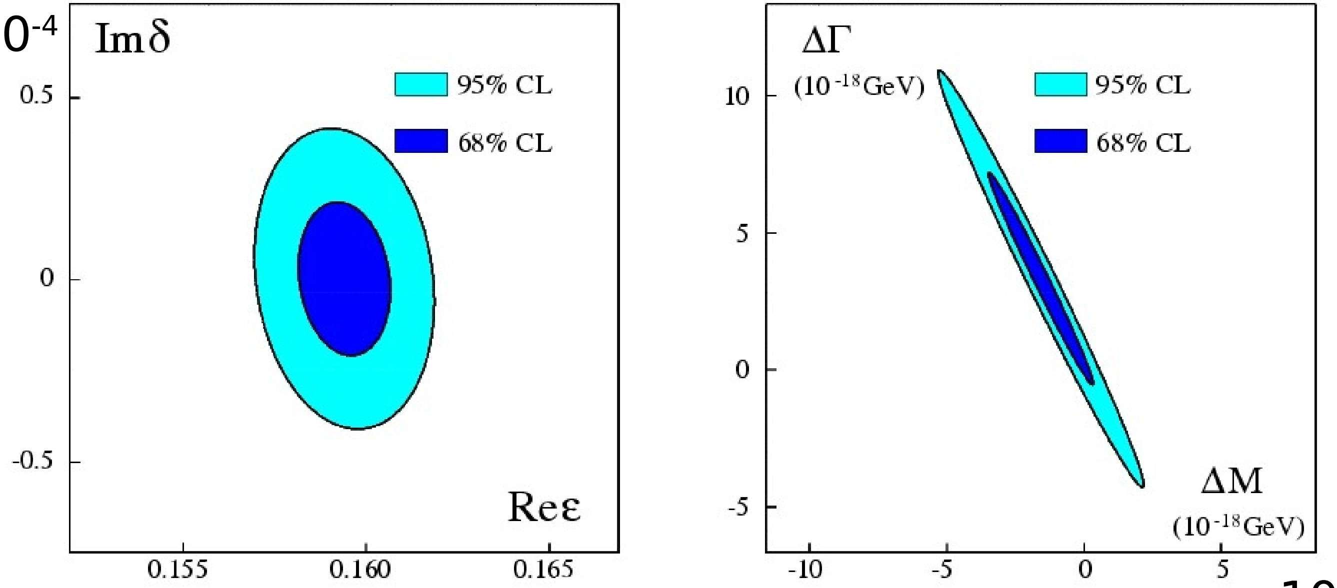
CP and CPT tests

Using the Bell-Steinberger relation

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

-5.3×10^{-19} GeV $< m_{K0} - m_{\overline{K0}} < 6.3 \times 10^{-19}$ GeV @ 95% C.L.

$\times 10^{-4}$



$\times 10^{-2}$ 10^{-18} GeV

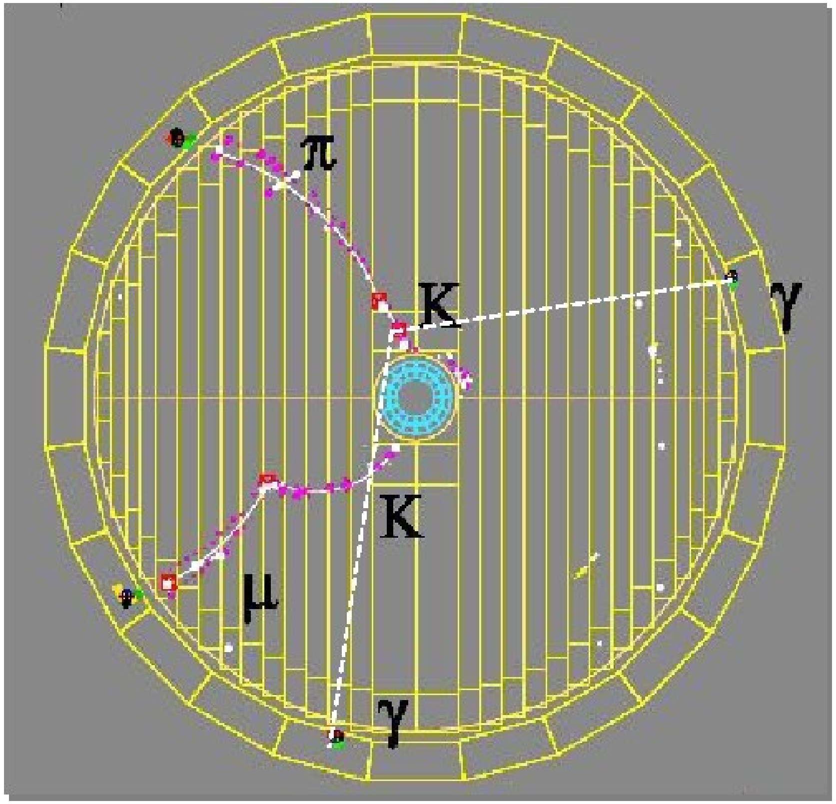
Charged kaons

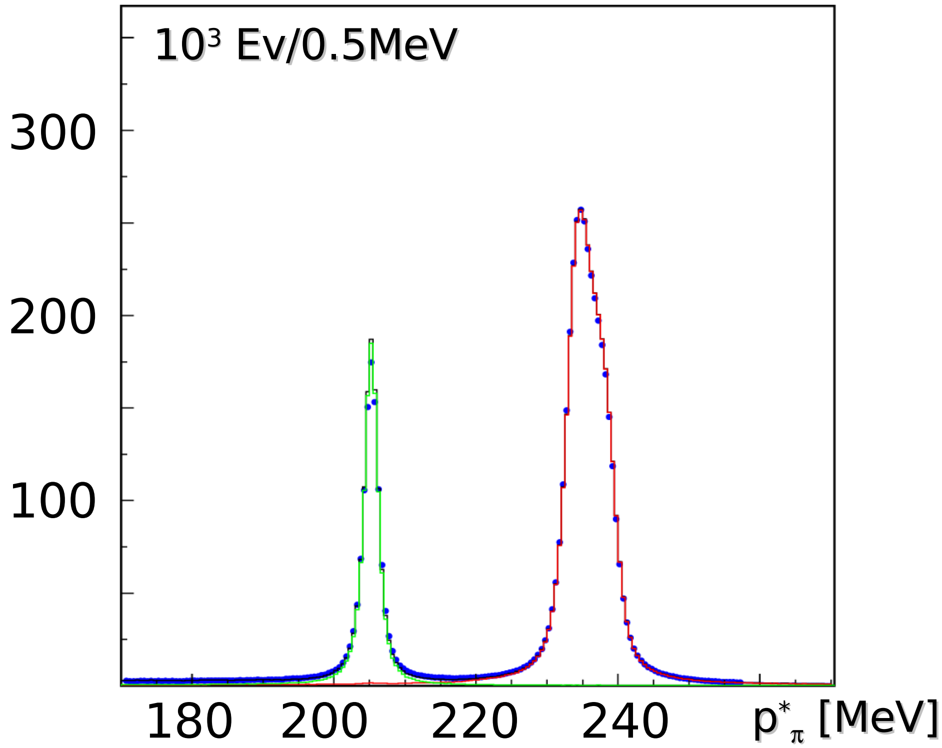
- **Lifetime**
- **Semileptonic decays**
- **$K^{\pm} \rightarrow \mu^{\pm} \nu_{\mu} (\gamma)$**

Data sample between 200 and 400 pb^{-1}

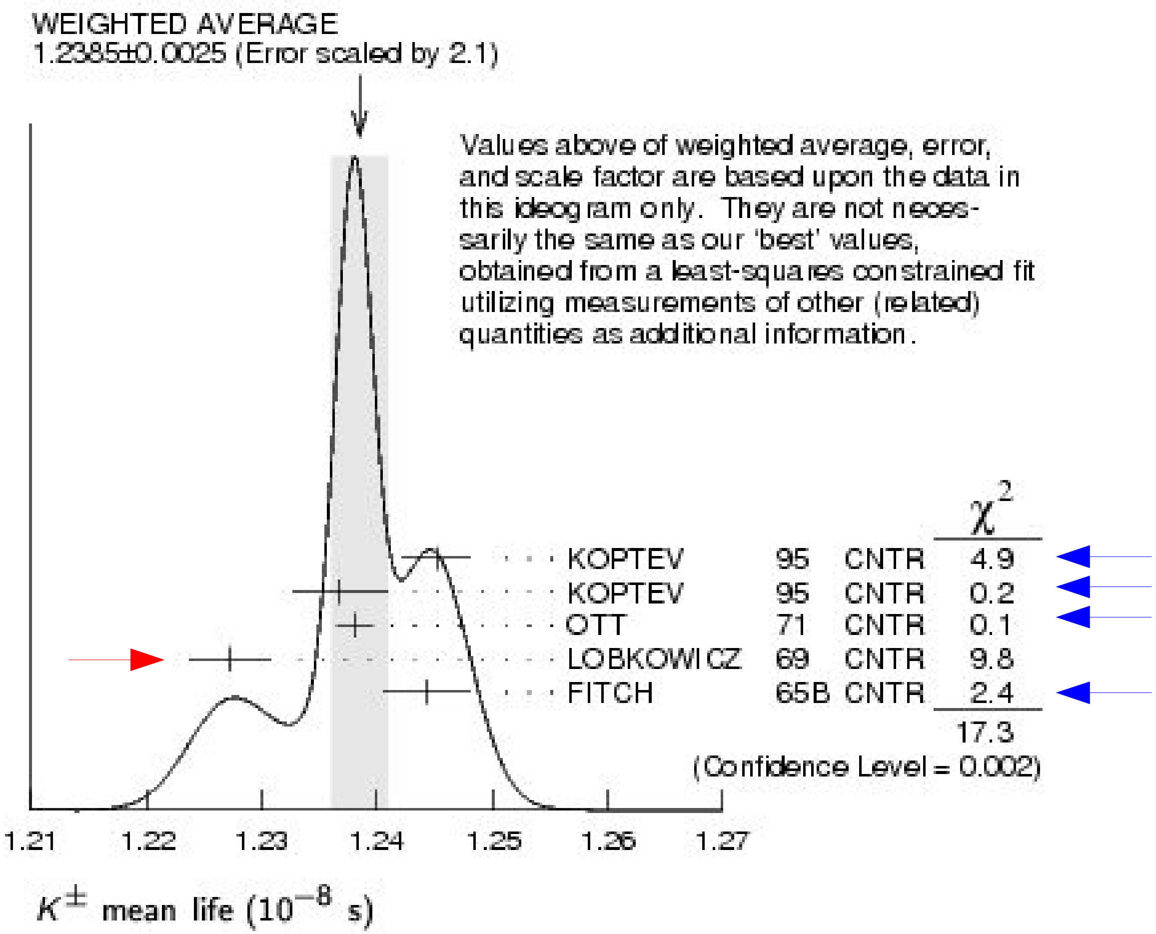
Tagging charged kaons

- two tracks of the same curvature
- secondary vertex in the fiducial volume
- two-body decay kinematics in the *K* frame
- tagging efficiency ≈ 36%





$K^{\pm}$ lifetime



Discrepancy between in-flight and at-rest measurements

Discrepancy among different stoppers in at-rest measurements

Confirmation is needed

$$\tau_{PDG} = (12.385 \pm 0.025)\ \text{ns}$$

$K^{\pm}$ lifetime

Given the tag, look for the decay vertex of the second kaon

- **Method #1: fit t^* distribution from decay length**
  Measure the kaon decay length taking into account the energy loss: $\tau^* = \Sigma_i \Delta L_i / \beta_i \gamma_i c$

$\tau_{\pm} = (12.367 \pm 0.044_{stat} \pm 0.065_{syst})$ ns **Preliminary**

- **Method #2: Directly measure decay time (in progress)** Use $K \rightarrow \pi \pi^0$ decay to reconstruct decay time from π^0 cluster time

Two methods allow cross check of systematics

$K^{\pm}$ semileptonic decays

- Fit of the charged secondary square mass spectrum m^2_{lept}
- Mass of charged secondary from p and TOF measurement
- π^0 reconstruction from 2 neutral clusters in EMC
- Separate measurements for each charge and each tag

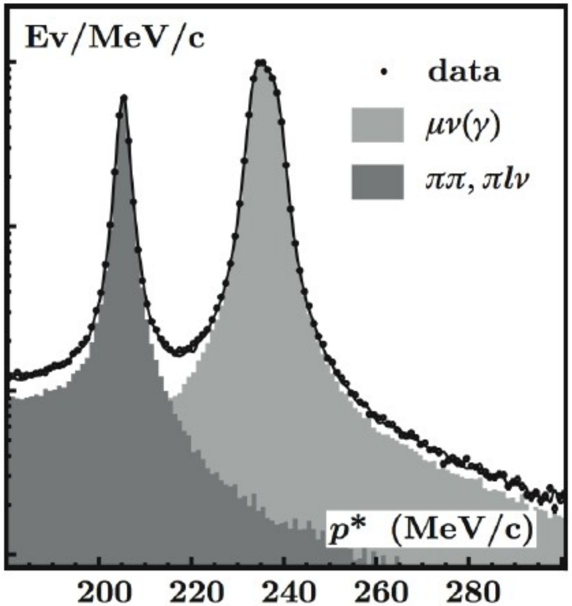
4 independent normalization samples

Preliminary

$BR(K^{\pm} \to \pi^0 e^{\pm} \nu_e) = (5.047 \pm 0.019 \pm 0.039) \times 10^{-2}$
$BR(K^{\pm} \to \pi^0 \mu^{\pm} \nu_{\mu}) = (3.310 \pm 0.016 \pm 0.045) \times 10^{-2}$

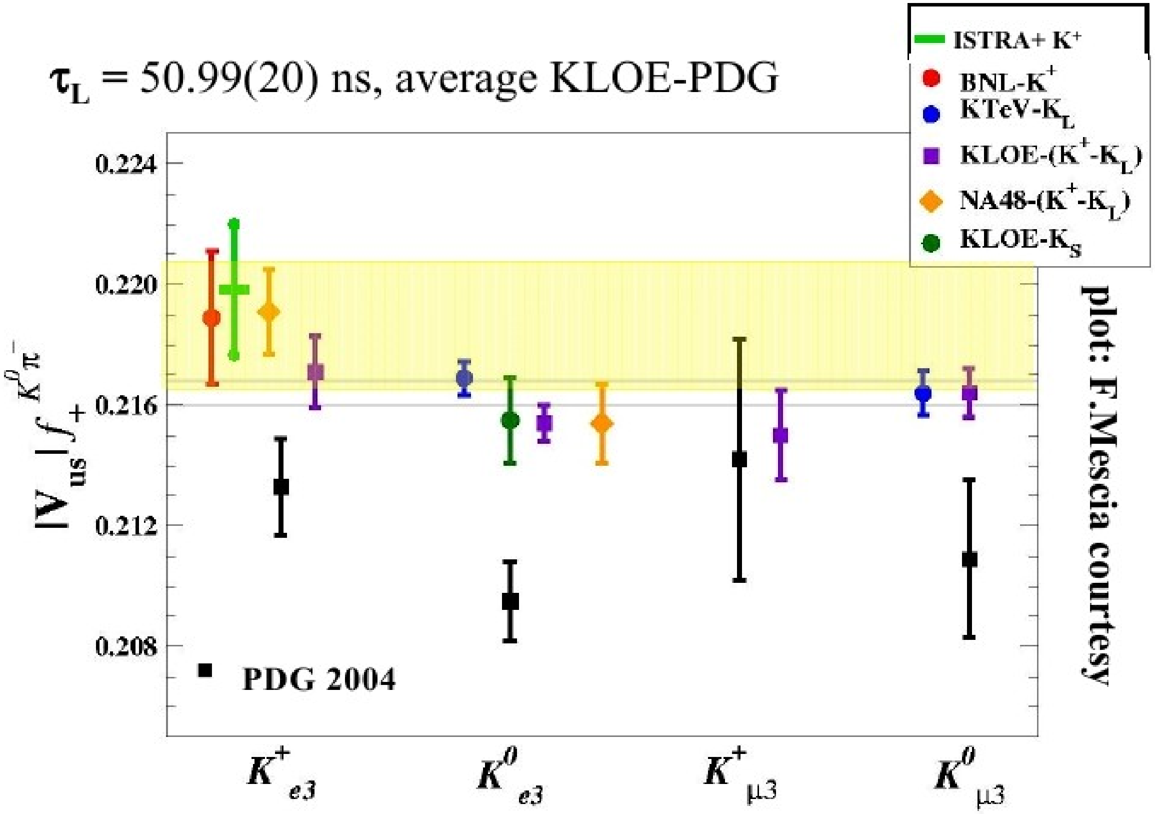
BR ($K^\pm \to \mu^\pm \nu_\mu(\gamma)$)

- Fit of the momentum distribution
  of the charged secondary, p*
- Background subtraction, π^0 in the final state
- Efficiency evaluated directly on data
  using uncorrelated sample
  selected using EMC info
- 8 x 10^5 events
- Total accuracy 0.27%



$$BR(K^\pm \to \mu^\pm \nu_\mu (\gamma)) = 0.6366 \pm 0.009 \pm 0.015$$

V_{us} summary



$<V_{us} \times f_+(0)>_{\text{WORD AV.}} = \mathbf{0.2164(4)}$

Slopes

$\lambda'_+ = 0.02542(31)$

$\lambda''_+ = 0.00129(3)$

(Pole model: KLOE, KTeV and NA48 av.)

$\lambda_0 = 0.01587(95)$

(KTeV and ISTRA+ av.)

From unitarity

- $f_+(0) = 0.961(8)$
  Leutwyler and Roos [Phys. **C25**, 91, 1984]
- Vud=0.97377(27)
  Marciano and Sirlin [Phys.Rev.Lett.96 032002,2006]

$$V_{us} \times f_+(0) = 0.2187(22)$$

V_{ud} - V_{us} plane

$|V_{us}/V_{ud}|$ can be extracted from the ratio: $\frac{\Gamma(K \to \mu\nu_\mu(\gamma))}{\Gamma(\pi \to \mu\nu_\mu(\gamma))} \propto \frac{|V_{us}|^2 f_K}{|V_{ud}|^2 f_\pi}$

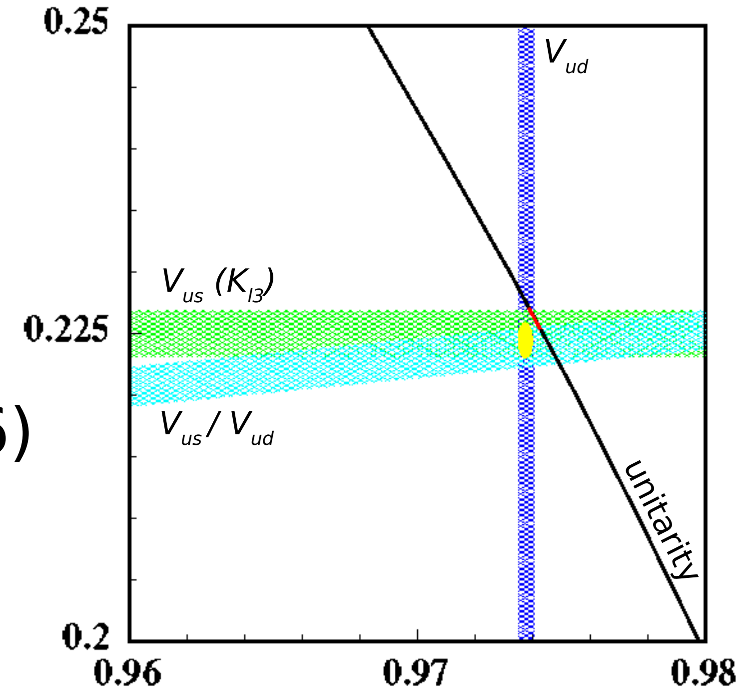
$\frac{f_K}{f_\pi} = 1.208(2)(^{+7}_{-14})$ from lattice MILC Coll. PoS LAT2006

$V_{us} / V_{ud} = 0.2286(^{+20}_{-11})$

Fitting with V_{ud}, V_{us} + unitarity constraint

$V_{us} = 0.2246(^{+9}_{-13})$
$V_{ud} = 0.97377(27)$
$\chi^2/\mathrm{dof} = 0.046/2$
$P(\chi^2) = 0.97$

$V_{us} = 0.2257(7)$
$V_{ud} = 0.97420(16)$
$\chi^2/\mathrm{dof} = 3.94/1$
$P(\chi^2) = 0.05$



Hadronic physics

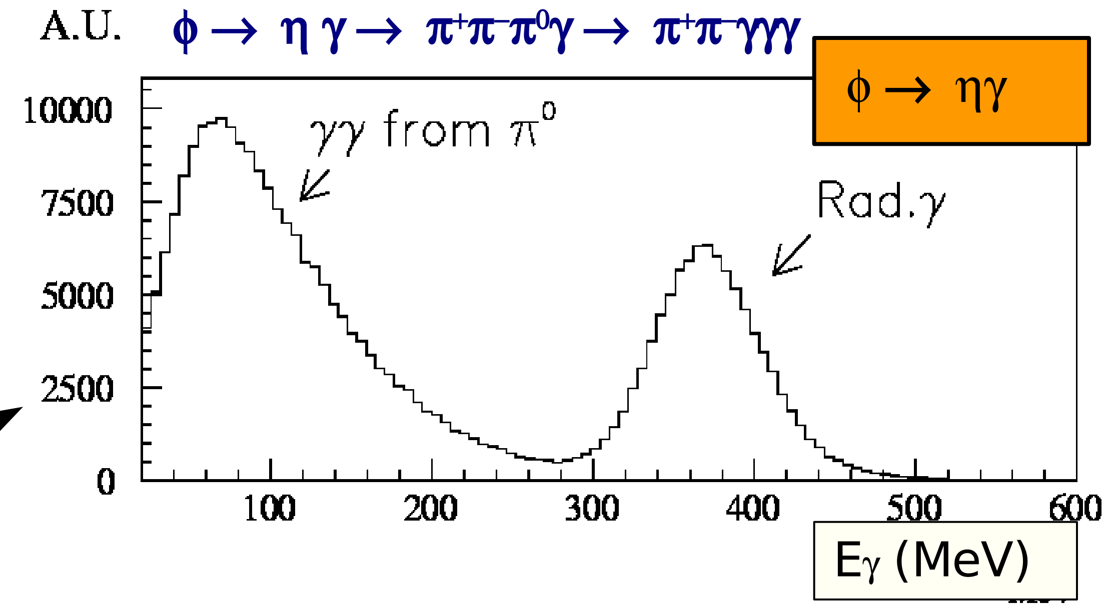
η and η' at KLOE

η/ η′ produced through transition $\phi \to P\gamma$

Monochromatic recoil photon very powerful for event ID

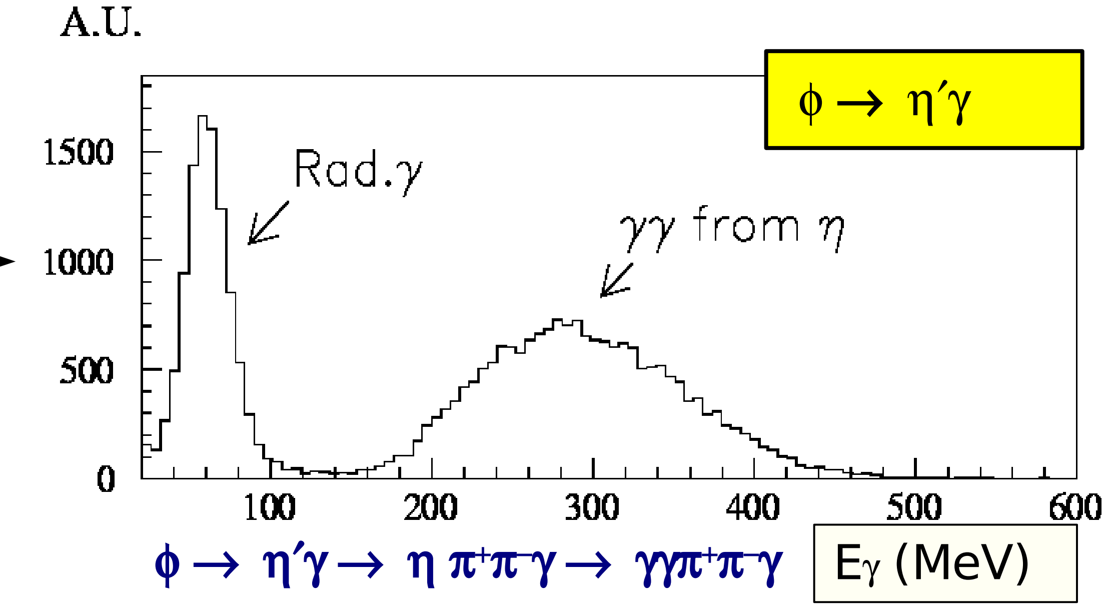
$E_{recoil}(\eta)$ = 363 MeV

very clean η sample



$E_{recoil}(\eta')$ = 60 MeV

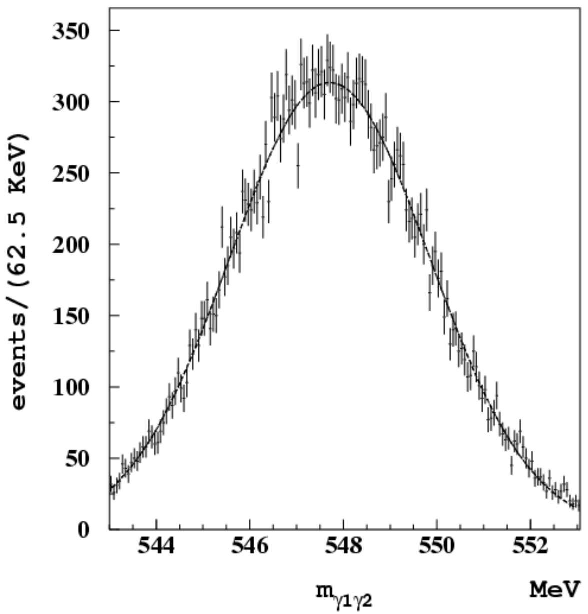
γ_{recoil} **mis-ID for some channels…**



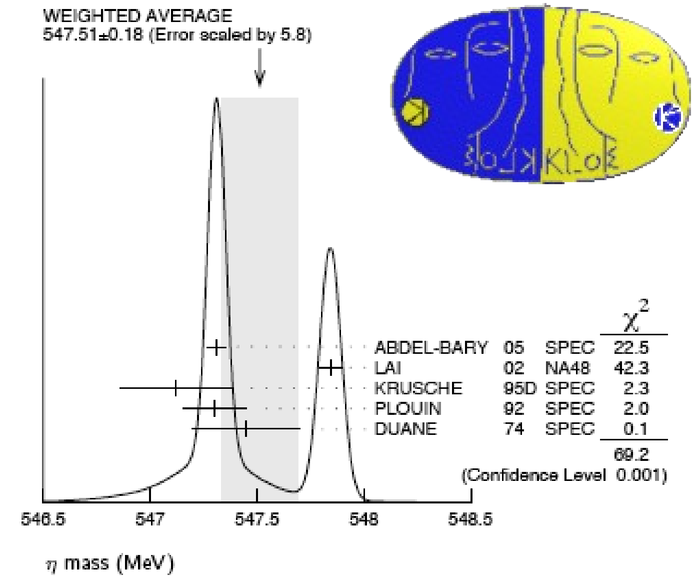
Results on η/η'

- η **mass**
- $\eta-\eta'$ **mixing angle**
- **Dynamics of** $\eta \to \pi^+\pi^-\pi^0$
- **Upper limit on** $\eta \to \pi^+\pi^-$
- **Upper limit on** $\eta \to \gamma\gamma$
- **BR(**$\eta \to \pi^0\gamma\gamma$**)**

η mass

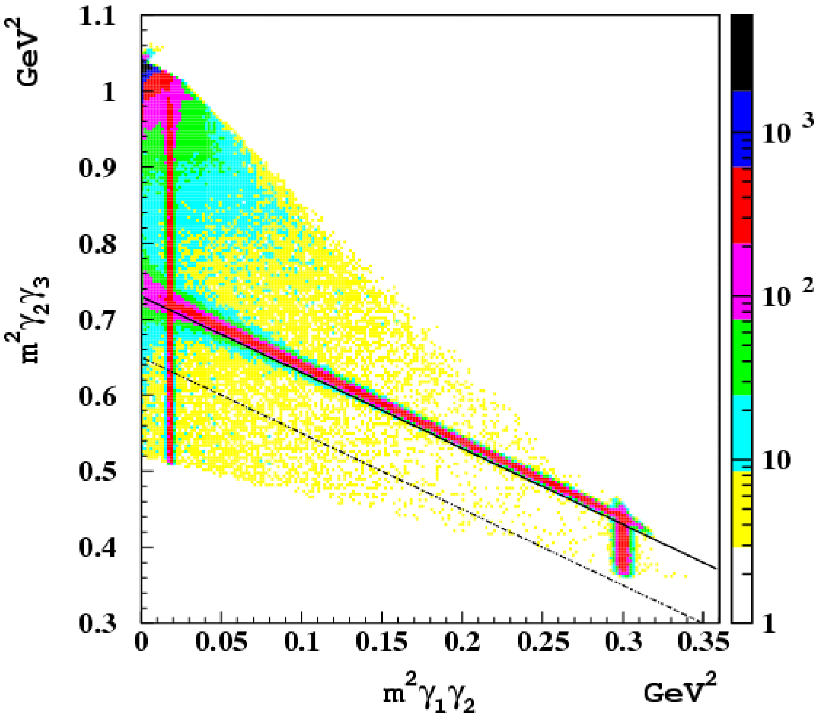


select $\phi \to \eta\gamma$; $\eta \to \gamma\gamma$



kinematic fit constraint:

- t – r / c of clusters
- 4-momenutm conservation



measured quantities:

- cluster x, y, z, E, t
- $x(\phi)$, $y(\phi)$, $z(\phi)$, $P(\phi)$, $\sqrt{s}$

$m(\pi^0) = (\ 134990 \pm 6 \pm 30\ )$ KeV

$m(\pi^0)_{PDG} = (\ 134976.6 \pm 0.6\ )$ KeV

Preliminary

$m(\eta) = (\ 547822 \pm 5 \pm 69\ )$ KeV

$BR(\phi\to\eta'\gamma)/BR(\phi\to\eta\gamma)$

Updated of already published result (3γ in the final state) **PLB 541(2002)**

Process: $\phi\to\eta'\gamma$ with $\pi^+\pi^-7\gamma$:

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

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

Normalization to $\phi\to\eta\gamma$ with $\eta\to\pi^0\pi^0\pi^0$

Very small physical background

Syst. different w.r.t. published result

$$R = \frac{BR(\phi\to\eta'\gamma)}{BR(\phi\to\eta\gamma)} = (4.77 \pm 0.09 \pm 0.19)\cdot 10^{-3}$$

Dominated by uncertainties on the intermediate BRs

With PDG $BR(\phi\to\eta\gamma)$: $BR(\phi\to\eta'\gamma) = (6.20 \pm 0.11 \pm 0.25)\cdot 10^{-5}$

$$|\eta\rangle = \cos\phi_P\,|q\bar{q}\rangle + \sin\phi_P\,|s\bar{s}\rangle$$
$$|\eta'\rangle = -\sin\phi_P\,|q\bar{q}\rangle + \cos\phi_P\,|s\bar{s}\rangle$$

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

TO BE SUBMITTED

$BR(\phi\to\eta'\gamma)/BR(\phi\to\eta\gamma)$

Using the approach by Bramon et al. [Eur. Phys. J. C7, 271(1999)] it is possible to evaluate the η' gluonium content via $\cos^2\phi_G$

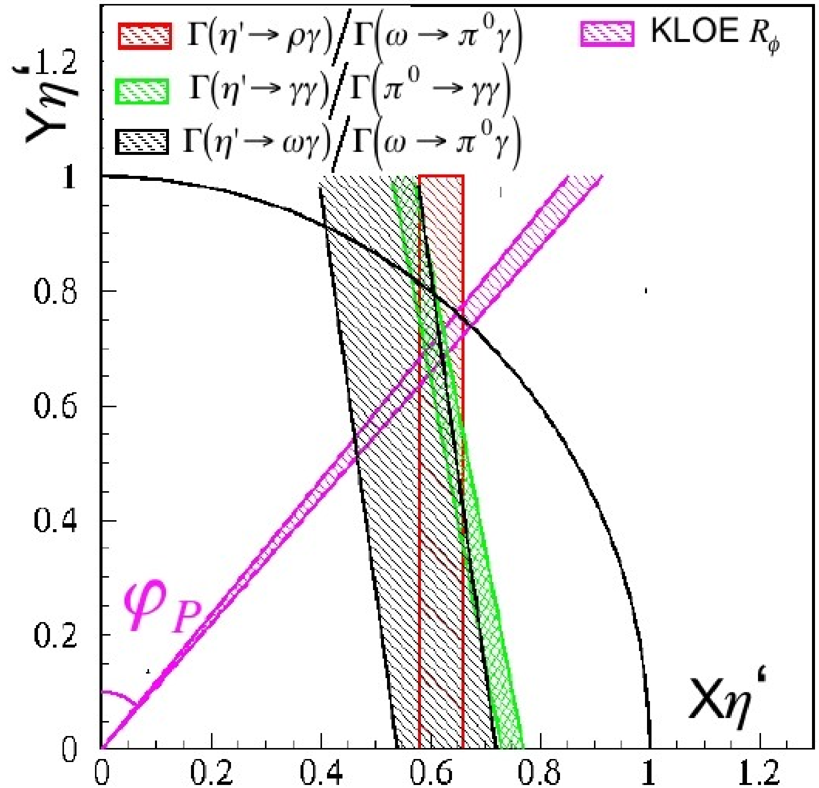
$$R_\phi = \cot^2\varphi_P \cos^2\phi_G \left(1 - \frac{m_s}{\bar{m}}\frac{C_{NS}}{C_S}\frac{\tan\varphi_V}{\sin 2\varphi_P}\right)^2 \left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

$$|\eta'\rangle = X_{\eta'}|q\bar{q}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_{\eta'}|\text{gluon}\rangle$$

$Z_{\eta'} = 0.14 \pm 0.04$

$\phi_P = (39.7 \pm 0.7)^\circ$

TO BE SUBMITTED



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

$$\Gamma(\eta \to 3\pi) \propto |A|^2 \propto Q^{-4}$$

$$A(s,t,u) = \frac{1}{Q^2}\frac{m_K^2}{m_\pi^2}(m_\pi^2 - m_K^2)\frac{M(s,t,u)}{3\sqrt{3}F_\pi^2}$$

With: $$Q^2 \equiv \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$$

And, at l.o. $$M(s,t,u) = \frac{3s - 4m_\pi^2}{m_\eta^2 - m_\pi^2}$$

$$|A(X,Y)|^2 = 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3$$

$$X = \sqrt{3}\frac{T_+ - T_-}{Q_\eta} = \frac{\sqrt{3}}{2M_\eta Q_\eta}(u-t)$$

$$Y = \frac{3T_0}{Q_\eta} - 1 = \frac{3}{2m_\eta Q_\eta}\left\{(m_\eta - m_{\pi^0})^2 - s\right\} - 1$$

Preliminary

- $a = -1.090 \pm 0.005\ ^{+0.008}_{-0.019}$
- $b = 0.124 \pm 0.006 \pm 0.010$
- → $c = 0.002 \pm 0.003 \pm 0.001$
- $d = 0.057 \pm 0.006\ ^{+0.007}_{-0.016}$
- → $e = -0.006 \pm 0.007\ ^{+0.005}_{-0.003}$
- $f = 0.14 \pm 0.01 \pm 0.02$

$P(\chi^2) = 0.75$ d.o.f.=149

More results on η decays

Upper limit on $\eta \to \pi^+\pi^-$

BR < 1.3 10^{-5} @90% C.L.

P and CP violating decay

SM prediction BR ~ $10^{-27} \div 10^{-24}$

PLB 606(2005) 276

Upper limit on $\eta \to \gamma\gamma\gamma$

BR < 1.6 10^{-5} @90% C.L.

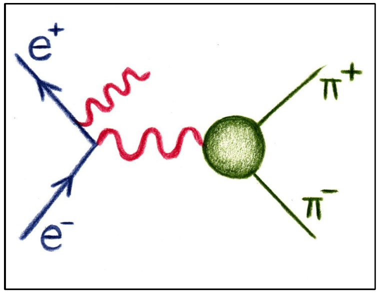
C violating decay

PLB 591(2004) 49

Preliminary

BR($\eta \to \pi^0\gamma\gamma$) = $(8.4 \pm 2.7 \pm 1.4) \cdot 10^{-5}$

A window on p^6 ChPT



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

PLB 606(2005) 12

KLOE measures $\sigma(e^+e^- \to \pi^+\pi^-)$ using the radiative return

No photon detection (small angle emission)

Measurement of differential cross section $d\sigma_{\pi\pi\gamma}/dM_{\pi\pi}^2$

s obtained using the raditor function $H(m_{\pi\pi}^2,s)$

$$\sigma(e^+e^- \to \pi^+\pi^-)\, H(m_{\pi\pi}^2, s) = m_{\pi\pi}^2 \left[\frac{d\sigma(\pi^+\pi^-\gamma)}{dm_{\pi\pi}^2}\right]_{ISR}$$

FSR accounted

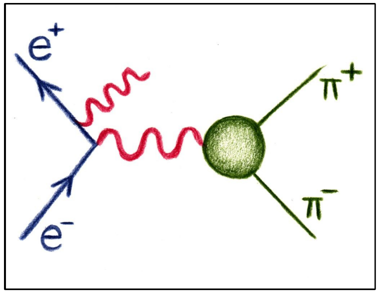
statistical error negligible

syst. error is 1.3%: 0.9% from measurement ; 0.9% from theory

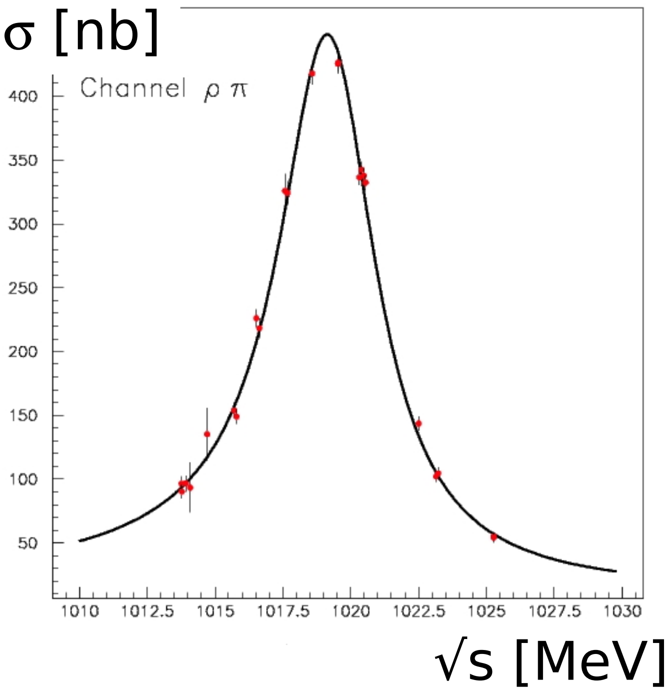
Evaluation of the hadronic contribution to the muon magnetic moment

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

Kernel function K(s) ~ 1/s



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



New analyses ongoing using:

- photon detection (large angle emission)
- 2002 data (published using only 2001)
- normalization to $\mu\mu\gamma$ events
- off-peak data

1000	200 pb^{-1}
1010	10 pb^{-1}
1018	10 pb^{-1}
1023	10 pb^{-1}
1030	10 pb^{-1}

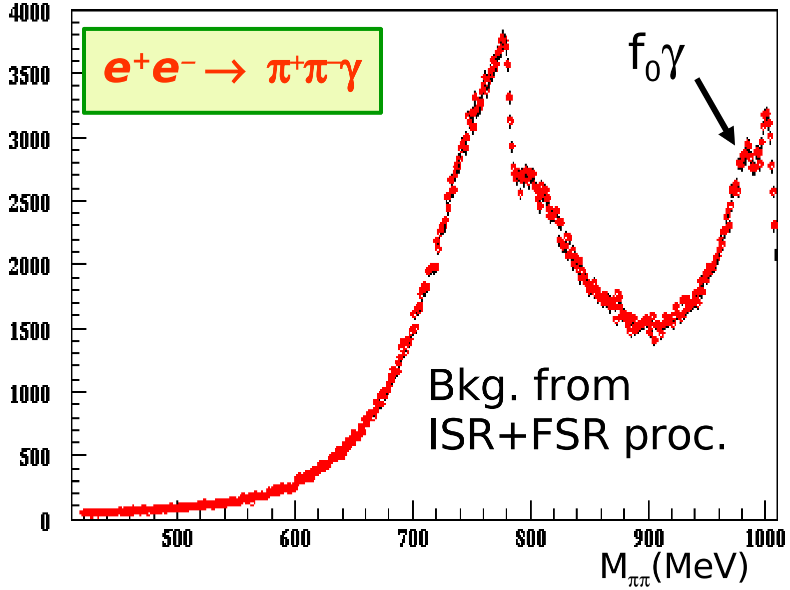
Since the end of 2005 DAΦNE has been running at $\sqrt{s} < m(\phi)$ collecting 240 pb^{-1}

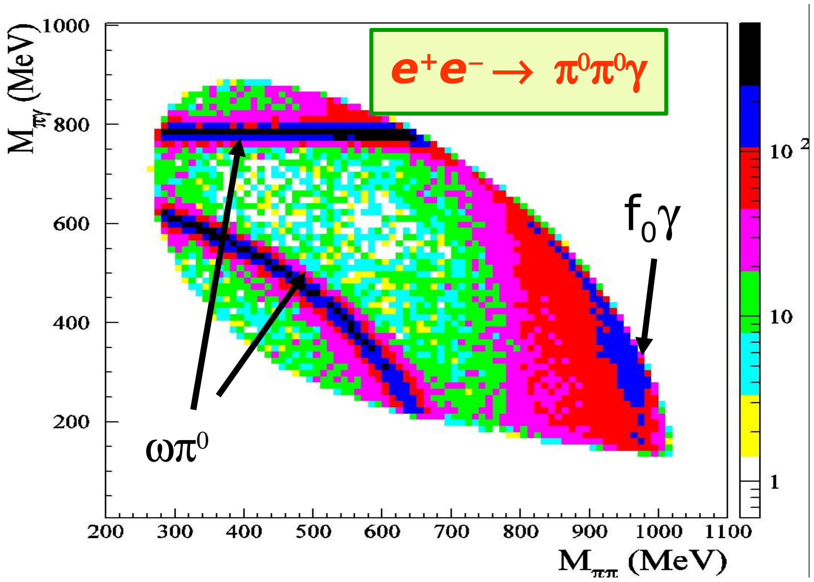
Reduction of $\phi \rightarrow \pi^+\pi^-\pi^0$ background at 1000 MeV bck ~5%

Results on f0

KLOE has studied the $f_0(980)$ through the decay chains

$\phi \to f_0\gamma \to \pi^+\pi^-\gamma$ **PLB 634 (2006) 148** $\phi \to f_0\gamma \to \pi^0\pi^0\gamma$ **Acc. by EPJ**





Data fitted with predictions from both Kaon-Loop model and direct scalar coupling to vector mesons (No-Structure)

Data can be described by both the models.

To fit the $\pi^0\pi^0\gamma$ spectrum with predictions from Kaon-loop model, a $\sigma(600)$ contribution must be included.

What's next?

Stay tuned!

A lot of analyses are on going

The analyses of data
collected in 2004 and 2005
~2 fb^{-1} are just begun

A short preview...

What's next?

Kaon physics

- Close to final results for K charged semileptonic
- BR($K_L \rightarrow \pi e \nu \gamma$) with $E_\gamma > 30$ MeV
- Scalar form factor λ_0 of $K_L \rightarrow \pi \mu \nu$ decay
- First measurement of $K_S \rightarrow \pi \mu \nu$
- Measurement of BR($K_S \rightarrow \gamma\gamma$)
- Measurement of BR($K^\pm \rightarrow \pi^\pm \pi^0$)
- Measurement of BR($K_S \rightarrow \pi^+ \pi^- \pi^0$), BR($K_S \rightarrow \pi^+ \pi^- e^+ e^-$)
- Improve on UL($K_S \rightarrow \pi^0 \pi^0 \pi^0$), UL($K_S \rightarrow e^+ e^-$)
- Improve on semileptonic BRs, lifetimes and form factors
- BR($K_L \rightarrow \pi\pi$) to few 10^{-3}
- $\Gamma(K^\pm \rightarrow e^\pm \nu)/\Gamma(K^\pm \rightarrow \mu^\pm \nu)$ to few 10^{-2}
- …

2 fb^{-1}

Hadronic physics

- Improved measurement for $\sigma_{\pi\pi}$
  - Large-Angle Photon analysis
  - Normalisation with $\mu\mu\gamma$ events
- η mass measurement
- Dalitz Plot of $\eta \to \pi\pi\pi$
- Upper Limit for BR($\eta \to \pi^0\pi^0$)
- Study of a_0(980)

- Measurement of $\sigma_{\pi\pi}$ without resonant background from ϕ
- Determination of f_0 and FSR parameters
- $\sigma(e^+e^- \to \omega\pi^0)$ vs. $\sqrt{s}$
- Search for σ(600) with off-peak data using the reaction $\gamma\gamma \to \pi^0\pi^0$

Off-peak data

- Combined fit of both charged and neutral $\pi\pi\gamma$ final states

  and searches for $f_0/a_0 \to$ KK
- Single and Double Dalitz η decays, $\eta \to \pi^0\gamma\gamma$, η' decays
- ...

2 fb^{-1}

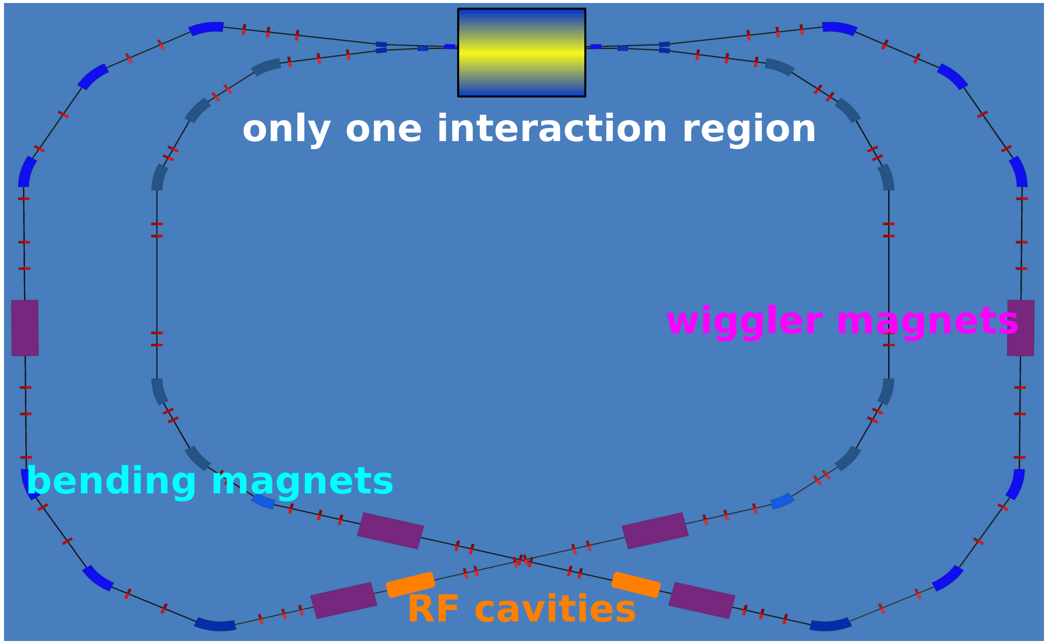
What's next? KLOE2

DAΦNE will run in 2006-07 for two other experiments:

FINUDA and SIDDHARTA

A new scheme to increase DAΦNE luminosity by a factor O(5) has been proposed by P.Raimondi (***crab waist collisions***)

It will be tested in autumn 2007 before the SIDDHARTA data taking



What's next? KLOE2

In autumn 2007 a modified optics according the new scheme will be tested

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

In the meantime the design of a higher energy machine ($\sqrt{s}$ up to 2.4 GeV) is continuing

The new machine will allow measurements of R, nucleon form factors, $\gamma\gamma$ physics, meson spectroscopy

Expressions of interest presented at the Laboratory this spring:

continuation of KLOE physics program at DAΦNE upgraded in luminosity and in energy

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 ($K \to e\nu$ / $K \to \mu\nu$) 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, $K_S \to \pi^+\pi^-\pi^0$, $K_S \to \pi^0\pi^0\pi^0$)

light mesons: structure of scalars (via $\gamma\gamma$ interaction), rare decays of pseudoscalars

$\sigma(e^+e^- \to$ hadrons), muon anomaly, evolution of α_{em}

baryon electromagnetic form factors, $e^+e^- \to pp$, nn, $\Lambda\Lambda$

… and more

*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**

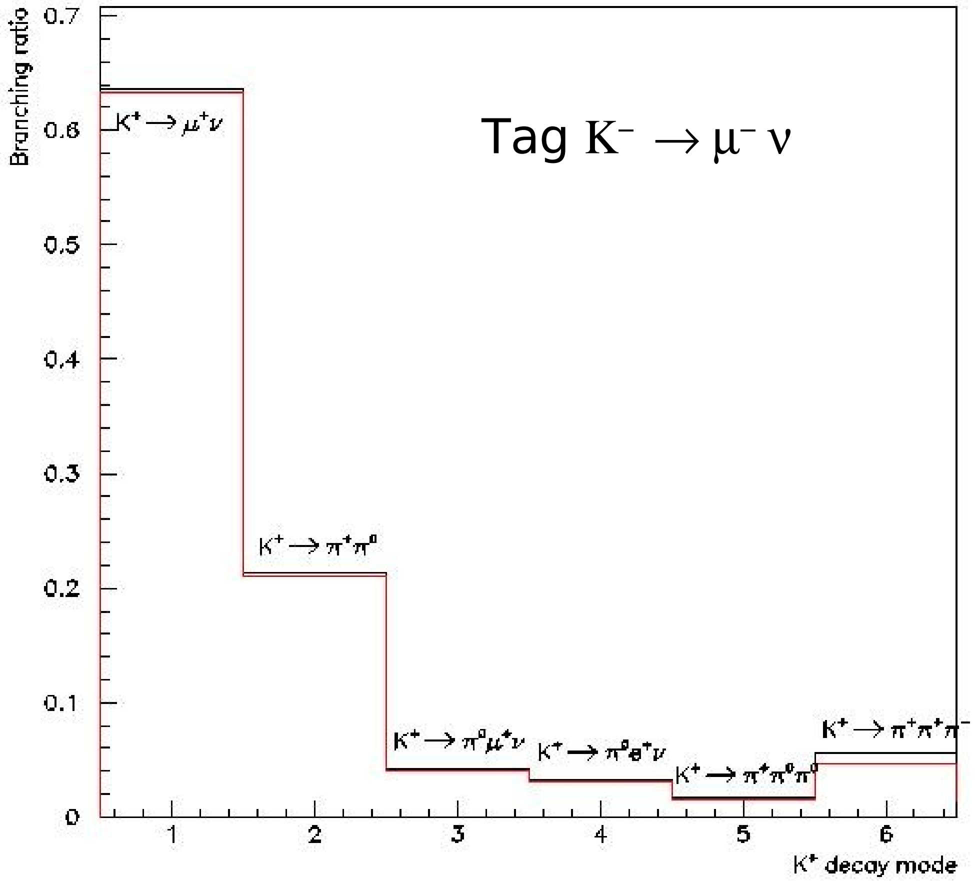
a new exciting challenge, who wants to join is welcome

Spare slides

Kaon physics

Tag bias

Measuring the BRs we must take into account a correction due to the bias on the signal sample induced by the tag selection **Tag bias**

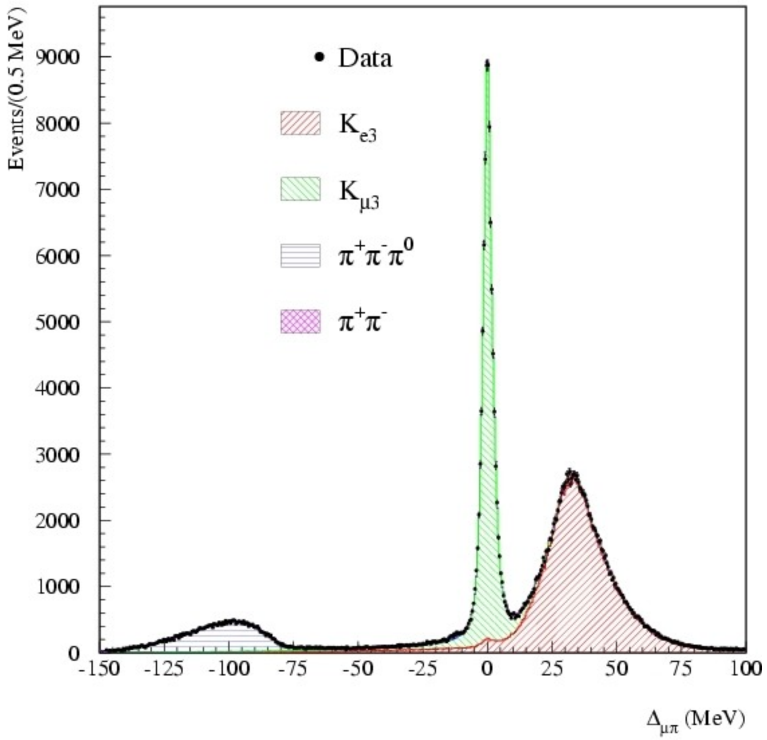


The correction C_{TB} is evaluated from MC and is given by:

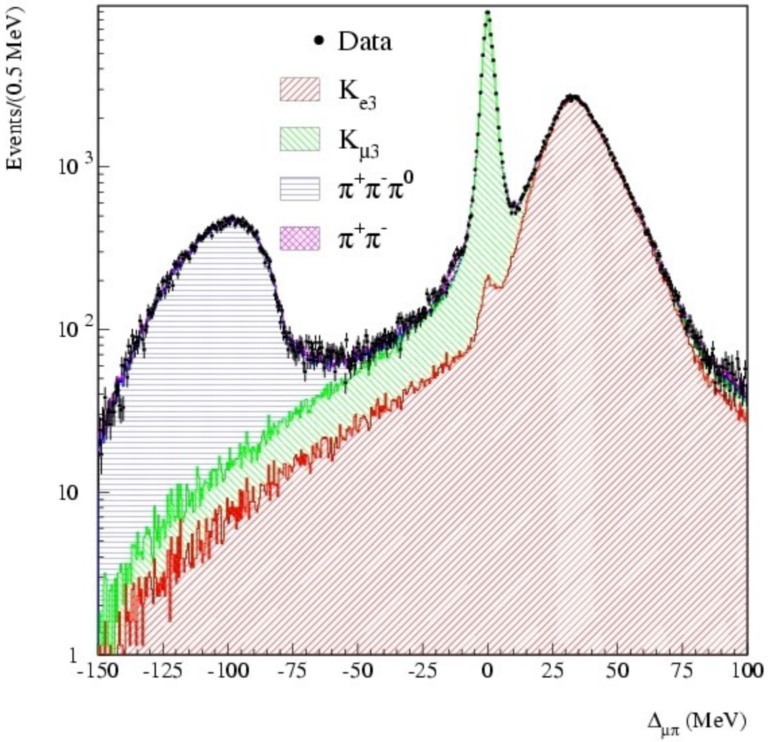
$$C_{TB} = BR_{MC}(\text{with tag}) / BR_{MC}(\text{without tag})$$

K_L selection

- 328 pb^{-1} split in 14 samples
- Tag given by $K_S \to \pi^+\pi^-$ ε_{Tag} ~63%
- K_L kinematic from K_S
- Best separation using $P_{miss} - E_{miss}$
- K_{e3} $K_{\mu3}$ separation using TOF & energy deposit in EMC
- 2γ invariant mass and timing



$P_{miss} - E_{miss}$



PLB 638 (2006) 140

$K_L \rightarrow \pi^+\pi^-(\gamma)$

$$|\eta_{+-}| = \sqrt{((\Gamma(K \rightarrow \pi^+\pi^-))/(\Gamma(K \rightarrow \pi^+\pi^-)))}$$

$$\eta_{+-} = \varepsilon + \varepsilon' \approx \varepsilon$$

$|\eta_{+-}|$ has been determined using:

- τ_{KL} from KLOE
- τ_{KS} from PDG'04
- $BR(K_S \rightarrow \pi^+\pi^-)$ from KLOE

$|\eta_{+-}| = (2.219 \pm 0.013) \times 10^{-3}$

ε has been determined using:

- $Re(\varepsilon'/\varepsilon)$ PDG'04
- $\arg \varepsilon' = \arg \varepsilon$

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

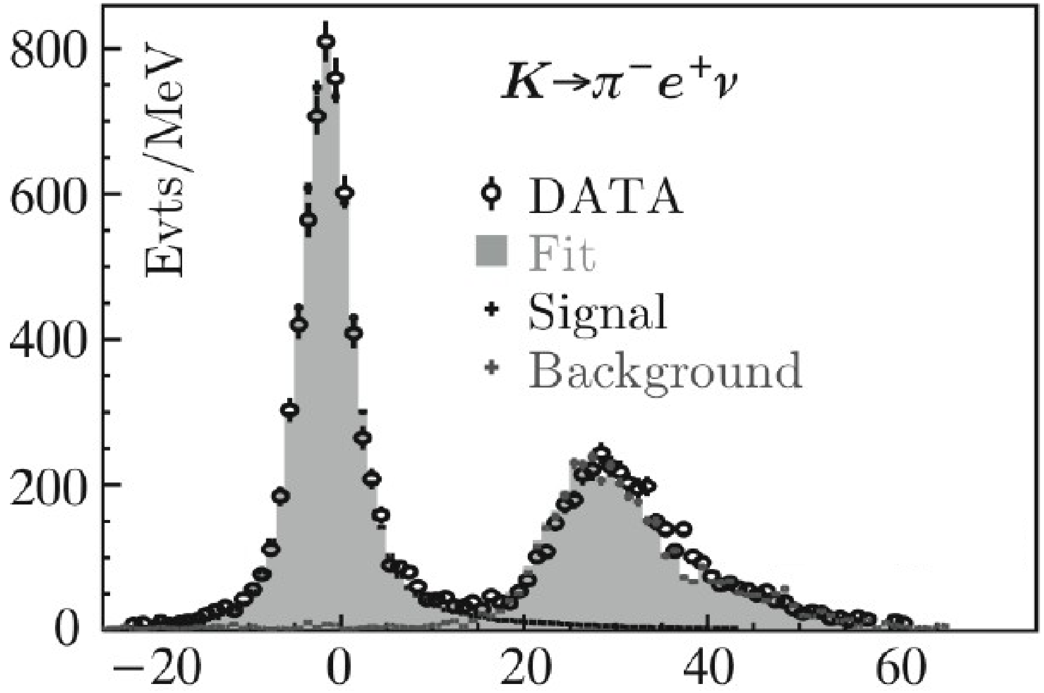
PLB 636 (2006) 173

$K_S \to \pi e \nu_e(\gamma)$

- Normalized to BR($K_S \to \pi^+\pi^-$)
- $K_S \to \pi^+\pi^-$ background

  rejected using TOF PID
- Signal from fit to

  $E_{miss} - P_{miss}$ spectrum



$E_{miss} - P_{miss}$

Allows test of CP, CPT and $\Delta S = \Delta Q$ rule

PLB 636 (2006) 173

$K_S \to \pi e \nu_e (\gamma)$

$$BR(K_S \to \pi^- e^+ \nu_e) = (3.528 \pm 0.062) \times 10^{-4}$$

$$BR(K_S \to \pi^+ e^- \nu_e) = (3.517 \pm 0.058) \times 10^{-4}$$

Consistent with $\Delta S = \Delta Q$ rule

Charge asymmetry A_S = (1.5 ± 9.6 ± 2.9) x 10-3

With full statistics (5x) KLOE will measure A_S to 3 x 10^{-3}

$$BR(K_S \to \pi e \nu_e) = (7.082 \pm 0.092) \times 10^{-4}$$

Linear slope of the form factor

λ_+ = (33.9 ± 4.1) x 10^{-3}

PLB 636 (2006) 173

$K_S \rightarrow \pi e \nu_e (\gamma)$

$$A_S = \frac{\Gamma(K_S \rightarrow \pi^- e^+ \nu_e) - \Gamma(K_S \rightarrow \pi^+ e^- \nu_e)}{\Gamma(K_S \rightarrow \pi^- e^+ \nu_e) - \Gamma(K_S \rightarrow \pi^+ e^- \nu_e)}$$

Comparison of charge asymeetries A_S and A_L allows tests of CP and CPT

Comparison of decay widths allows test of $\Delta S = \Delta Q$ rule

$A_S - A_L = 4\,(\mathrm{Re}\,\delta + \mathrm{Re}\,x\_)$

$A_S + A_L = 4\,(\mathrm{Re}\,\varepsilon - \mathrm{Re}\,y)$

$2\,\mathrm{Re}\,x_+ = (\Gamma_S - \Gamma_L) / (\Gamma_S + \Gamma_L)$

$\mathrm{Re}\,x_+ = (-1.2 \pm 3.6) \times 10^{-3}$

$\mathrm{Re}\,x\_ = (-0.8 \pm 2.5) \times 10^{-3}$

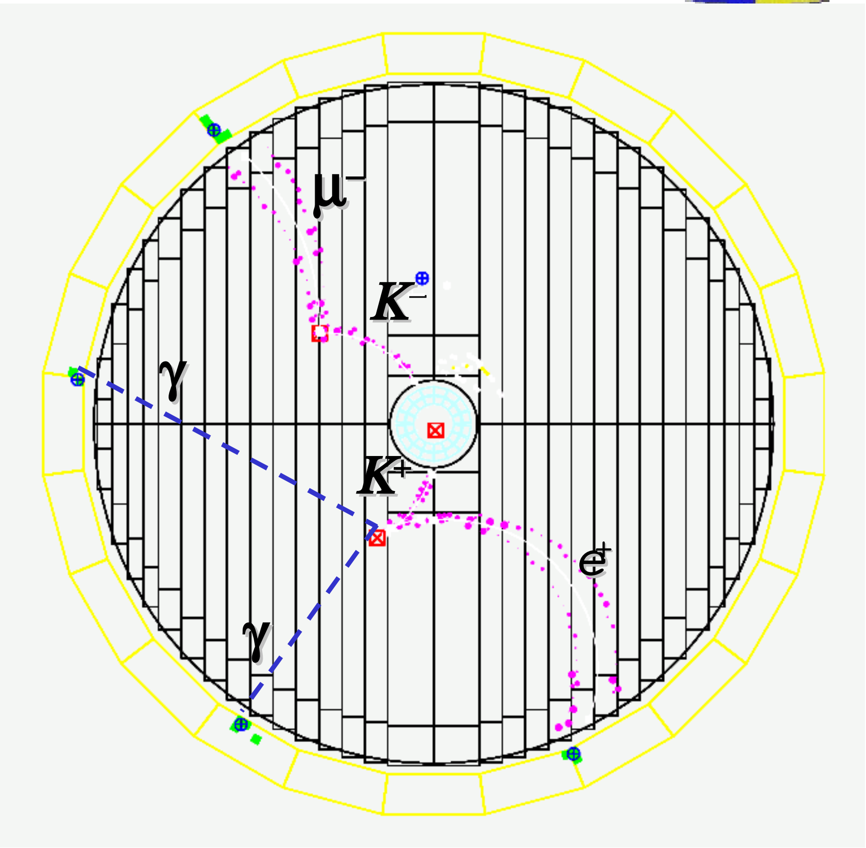
$\mathrm{Re}\,y = (0.4 \pm 2.5) \times 10^{-3}$

$K^{\pm}$ semileptonic decays

- 4 independent normalization samples (2 tag x 2 charges)
- 410 pb^{-1} self-triggering tags from 2001 and 2002 data
- Fit of the charged secondary square mass spectrum m^2_{lept}
- $K^{\pm} \rightarrow \mu^{\pm}\nu_{\mu}$ and $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ rejected cutting on $p^*(m_{\pi})$
- Efficiency evaluated from MC and
  corrected for Data/MC ratio

$K^{\pm}_{l3}$ signal selection

- Two tracks vertex in the FV:
  40 cm < ρ < 150 cm
- Track of charged secondary
  extrapolated to EMC
- Two body decays cut:
  $p^*(m_\pi) < 195$ MeV/c
- π^0 reconstruction:
  2 neutral clusters in EMC
  with TOF matching the
  kaon decay vertex
- Mass of charged secondary
  from TOF measurement



$$t_{\pi^0}^{decay} = \frac{(t_1 - L_1/c) + (t_2 - L_2/c)}{2}$$

$$m_{lept}^2 = p_{lept}^2 \cdot \left[\frac{c^2}{L_{lept}^2} (t_{lept} - t_{\pi^0}^{decay})^2 - 1 \right]$$

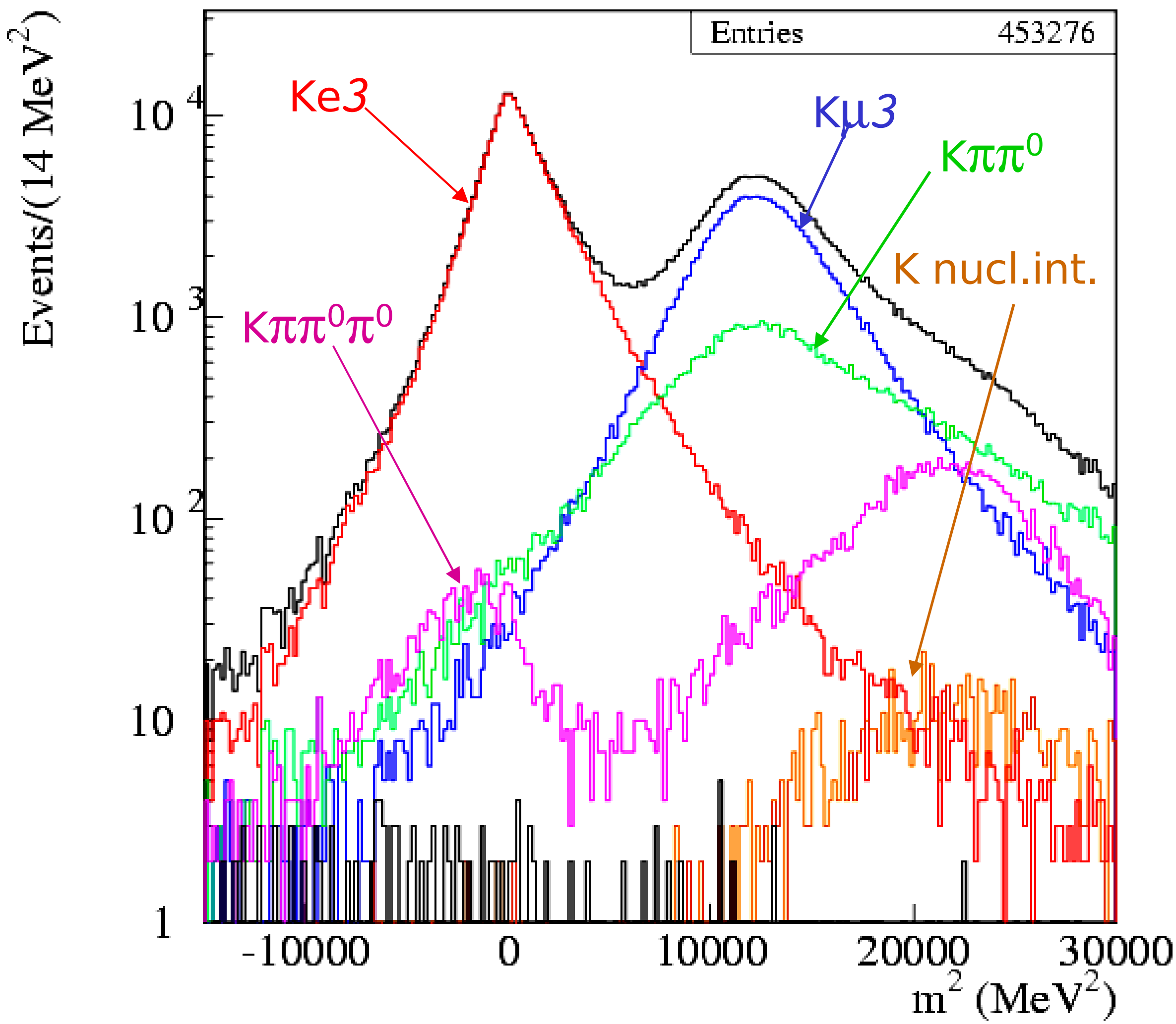
$K^{\pm}_{l3}$ background (I)

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ with a π^{0} undergoing a Dalitz decay, or with a wrong cluster associated to $\pi^{\pm}$, give a m_l^2 under the Ke3 peak

$\Rightarrow$ cut requiring $(E_{miss} - P_{miss}) < 90$ MeV

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ with early $\pi^{\pm} \rightarrow \mu^{\pm}\nu$, give m_l^2 under the Kμ3 peak

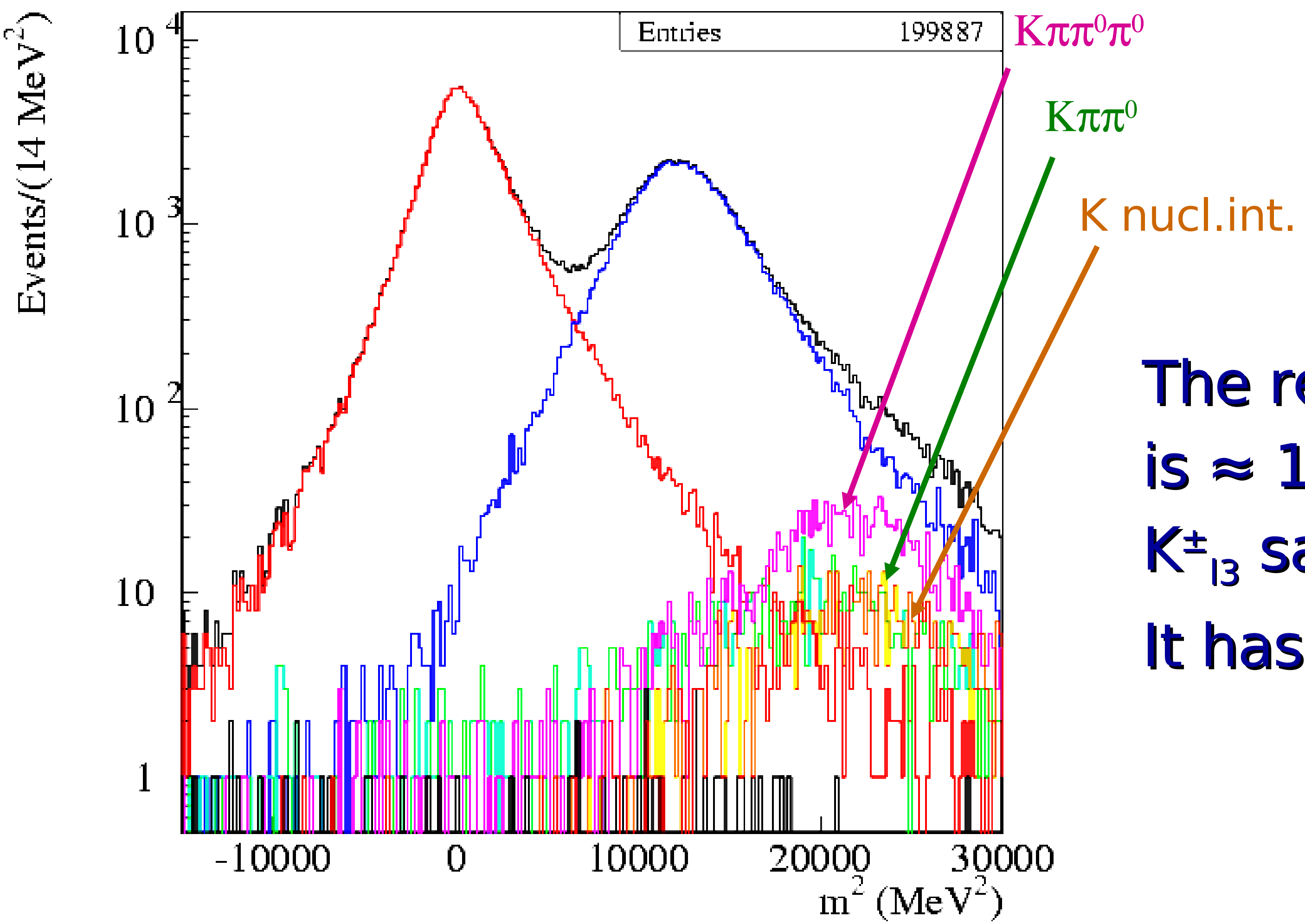
$\Rightarrow$ rejected using the missing momentum of the secondary track in the pion rest frame ($P^*_{sec} < 90$ MeV)



$K^{\pm}_{l3}$ background (II)

The cuts reject ≈ 96% of the background events

The efficiency on the signal is ≈ 50% for both K_{e3} and $K_{\mu3}$

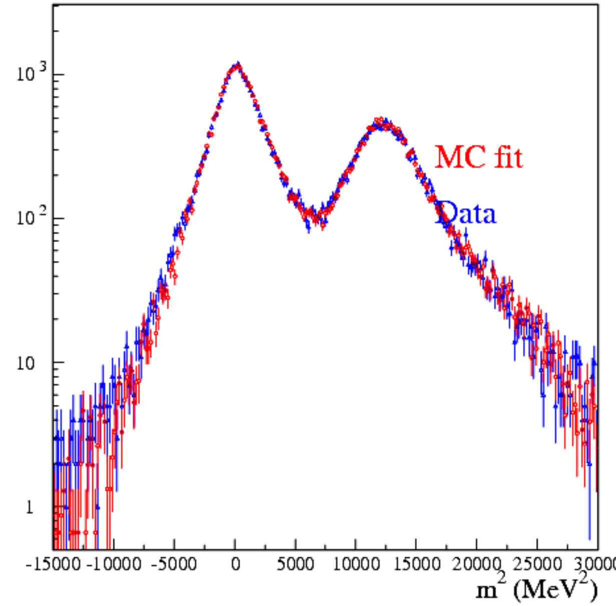


The residual background is ≈ 1.5% of the selected $K^{\pm}_{l3}$ sample.

It has $m_{lept}^2 \approx m_{\pi}^2$

$K^{\pm}$ semileptonic decays

Fit m^2_{lept} spectrum with linear combination of Ke3 , Kμ3 shapes, and bck contribution. Average of the four data samples.



- **Fractional accuracy:**

  0.9% for K_{e3} ; 1.2% for $K_{\mu 3}$

- **Systematic error studies to be completed**
- Dominated by the **knowledge of selection efficiency**

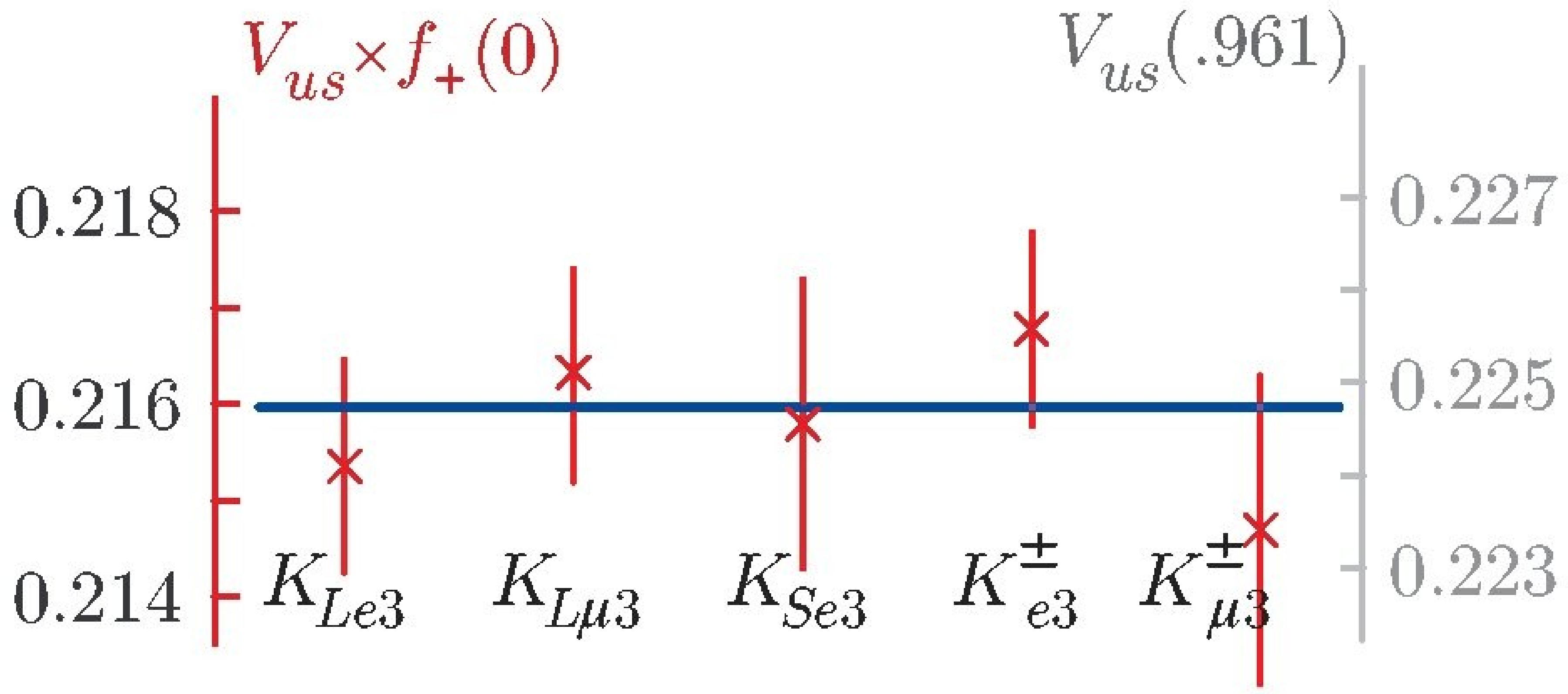
$BR(K^{\pm} \rightarrow \pi^0 e^{\pm} \nu_e) = (5.047 \pm 0.019 \pm 0.039) \times 10^{-2}$
$BR(K^{\pm} \rightarrow \pi^0 \mu^{\pm} \nu_{\mu}) = (3.310 \pm 0.016 \pm 0.045) \times 10^{-2}$

V_{us} from semileptonic decays

$$\tau(K_L) = 50.84 \pm 0.23$$

$$\langle V_{us} \times f_+(0) \rangle_{\mathbf{KLOE}} = 0.2160 \pm 0.0005$$

$$\chi^2/\mathrm{dof} = 1.9/4$$



from V_{ud} and unitarity: $V_{us} \times f_+(0) = 0.2187 \pm 0.0022$

Hadronic physics

Upper limit $\eta \to \pi^+\pi^-$

P and CP violating decay

Standard Model prediction BR ~ $10^{-27} \div 10^{-24}$

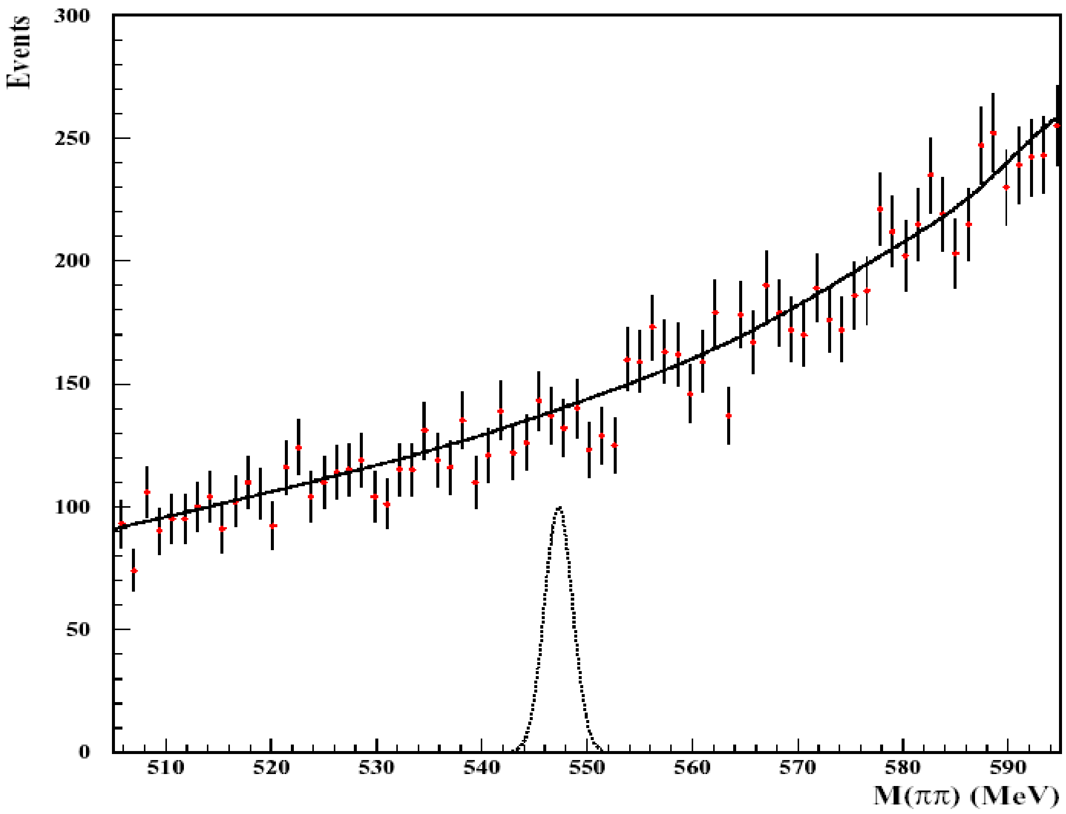
Analysis: “by product” of $f_0 \to \pi^+\pi^-$ analysis

ε=16.6%

Normalization to $\eta \to 3\pi^0$

BR < 1.3 10^{-5} @90% C.L.

PLB 606(2005) 276



$\eta \to \pi \pi \pi$ dynamics

Why the experimental width is so large (270 eV) w.r.t theoretical calculation (66 eV @ tree level) ?

Possible answers:

- Final state interaction
- Scalar intermediate states
- Violation of Dashen theorem

Check the description of the dynamics for both $\pi^+\pi^-\pi^0$ and $3\pi^0$ final states !

$\eta \to 3\pi$ at KLOE

At KLOE η is produced in the process $\phi \to \eta\gamma$.

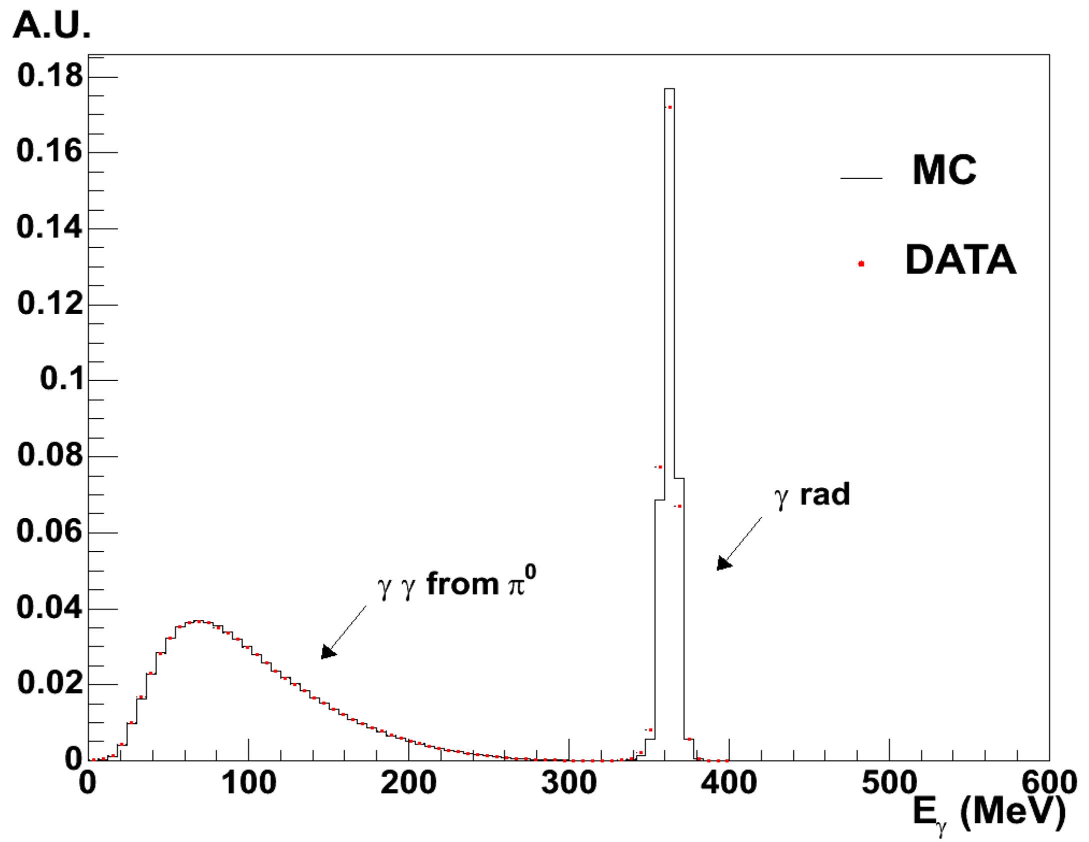
The final state for $\eta \to \pi^+\pi^-\pi^0$ is thus $\pi^+\pi^-\gamma\gamma$

and the final state for $\eta \to \pi^0\pi^0\pi^0$ is 7γ,

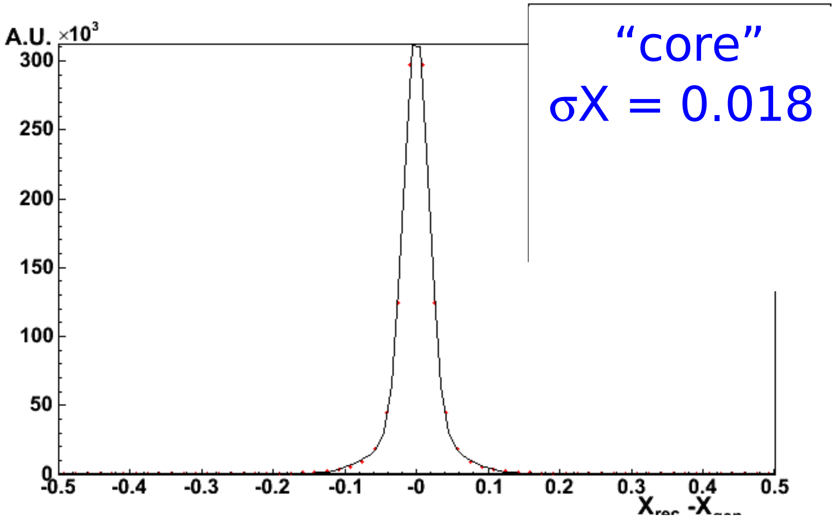
both with almost no physical background.

$\pi^+\pi^-\pi^0$ selection:

- 2 track vertex+3 γ candidates
- Kinematic fit

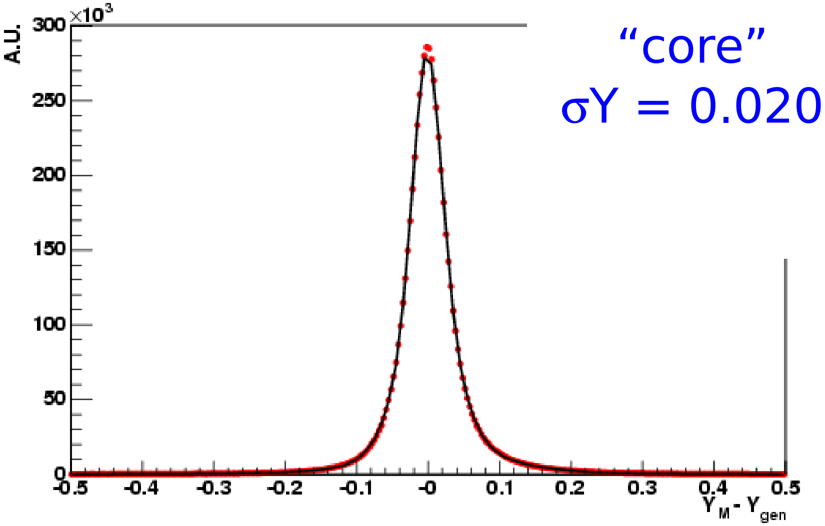


$\pi^+\pi^-\pi^0$: resolution and efficiency

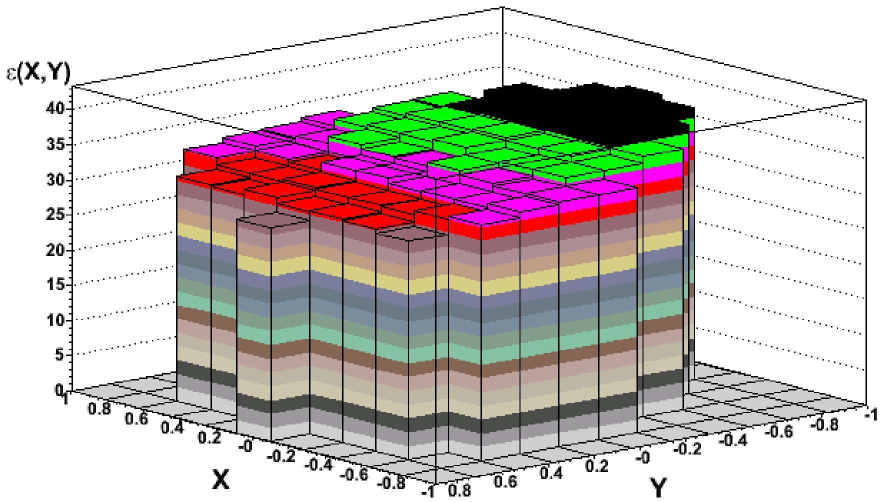


$$X = \sqrt{3}\,\frac{T_+ - T_-}{Q_\eta} = \frac{\sqrt{3}}{2M_\eta Q_\eta}(u-t)$$

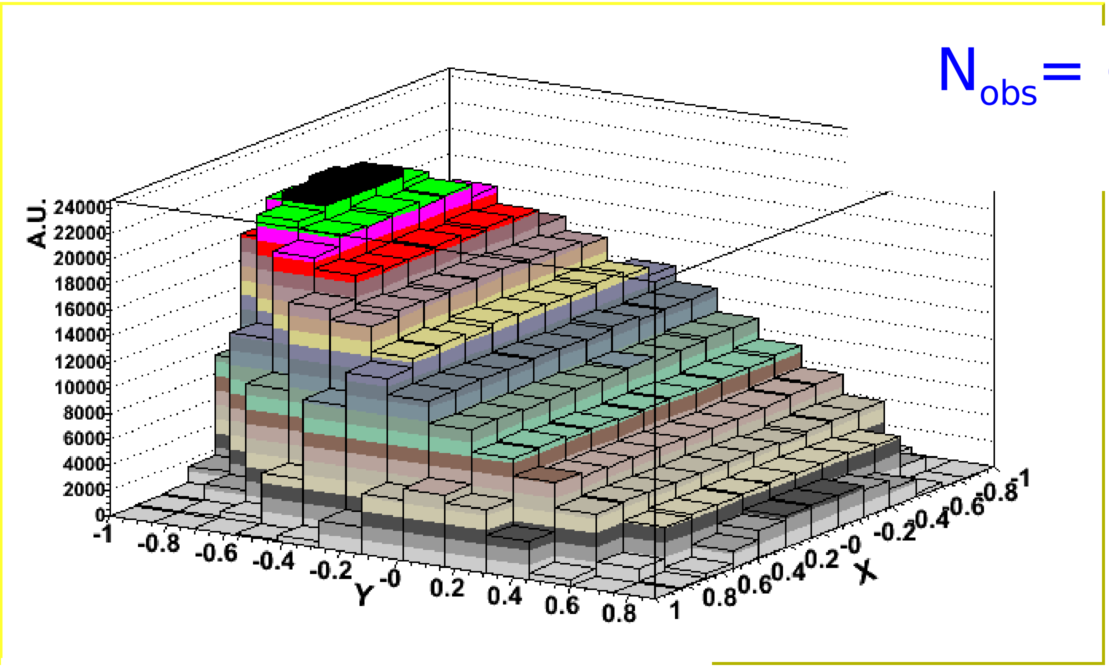
$$Y = \frac{3T_0}{Q_\eta} - 1 = \frac{3}{2m_\eta Q_\eta}\left\{\left(m_\eta - m_{\pi^0}\right)^2 - s\right\} - 1$$



Efficiency almost flat, and ~ 35%

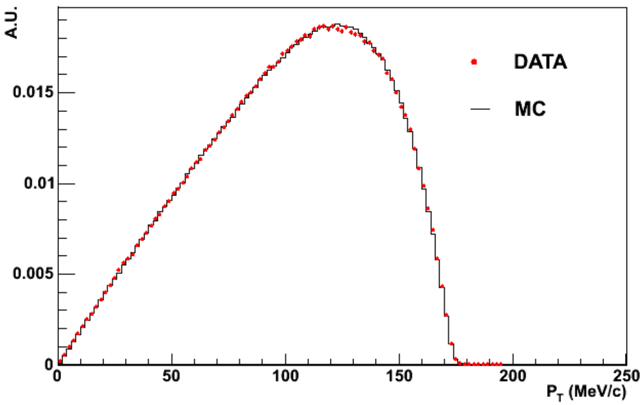


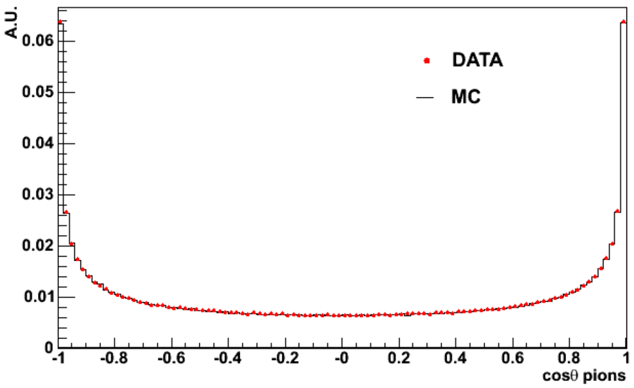
Signal



N_{obs}= (1.377±0.001)×10^6

B/S ~ 0.3%





Results

$$|A(X,Y)|^2 = 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3$$

$$a = -1.090 \pm 0.005(stat)^{+0.008}_{-0.019}(syst)$$

$$b = 0.124 \pm 0.006(stat) \pm 0.010(syst)$$

$$d = 0.057 \pm 0.006(stat)^{+0.007}_{-0.016}(syst)$$

$$f = 0.14 \pm 0.01(stat) \pm 0.02(syst)$$

~~C~~

$$c = 0.002 \pm 0.003(stat) \pm 0.001(syst)$$

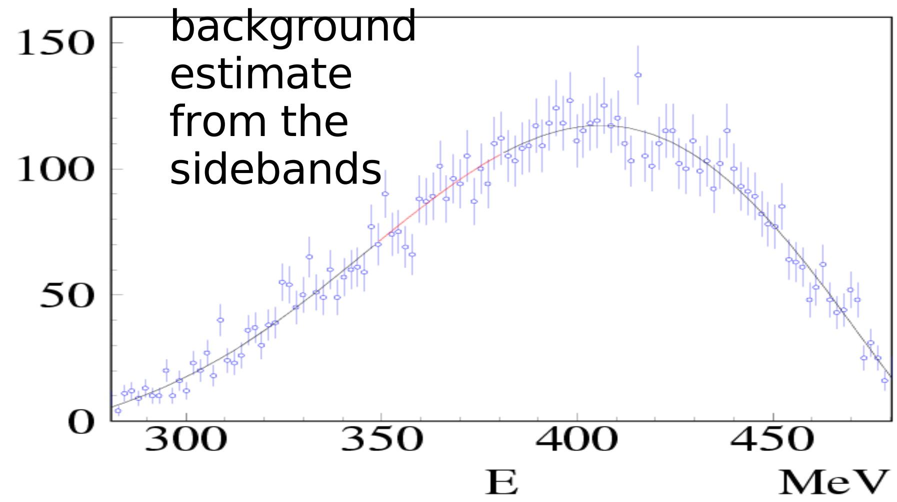
$$e = -0.006 \pm 0.007(stat)^{+0.005}_{-0.003}(syst)$$

Search for $\eta \to \gamma\gamma\gamma$

Violates C
BR < 5×10^{-4} @95%CL
PDG '02 (GAMS2000)

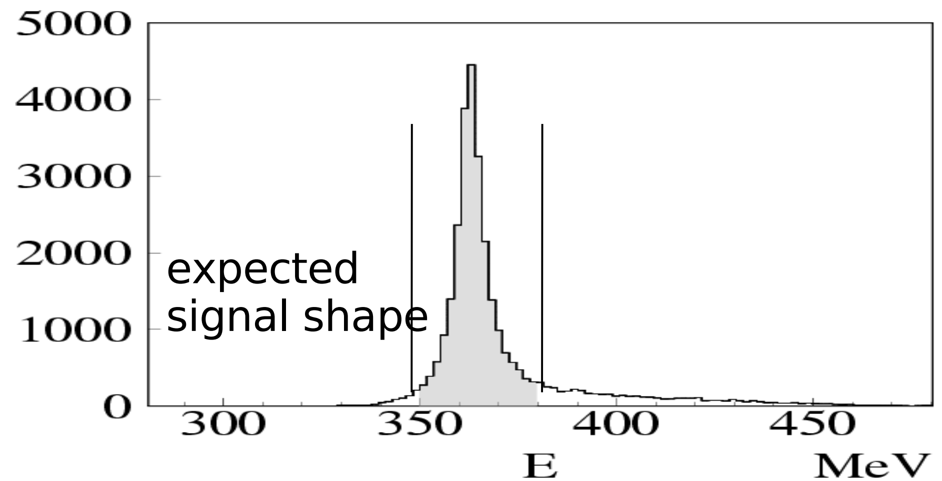
$\phi \to \eta\,\gamma \to 4\gamma$

- E_{recoil} = 363 MeV
- $\gamma\gamma\gamma$



BR($\eta \to 3\gamma$) $\leq 1.6\times10^{-5}$ @ 90% CL

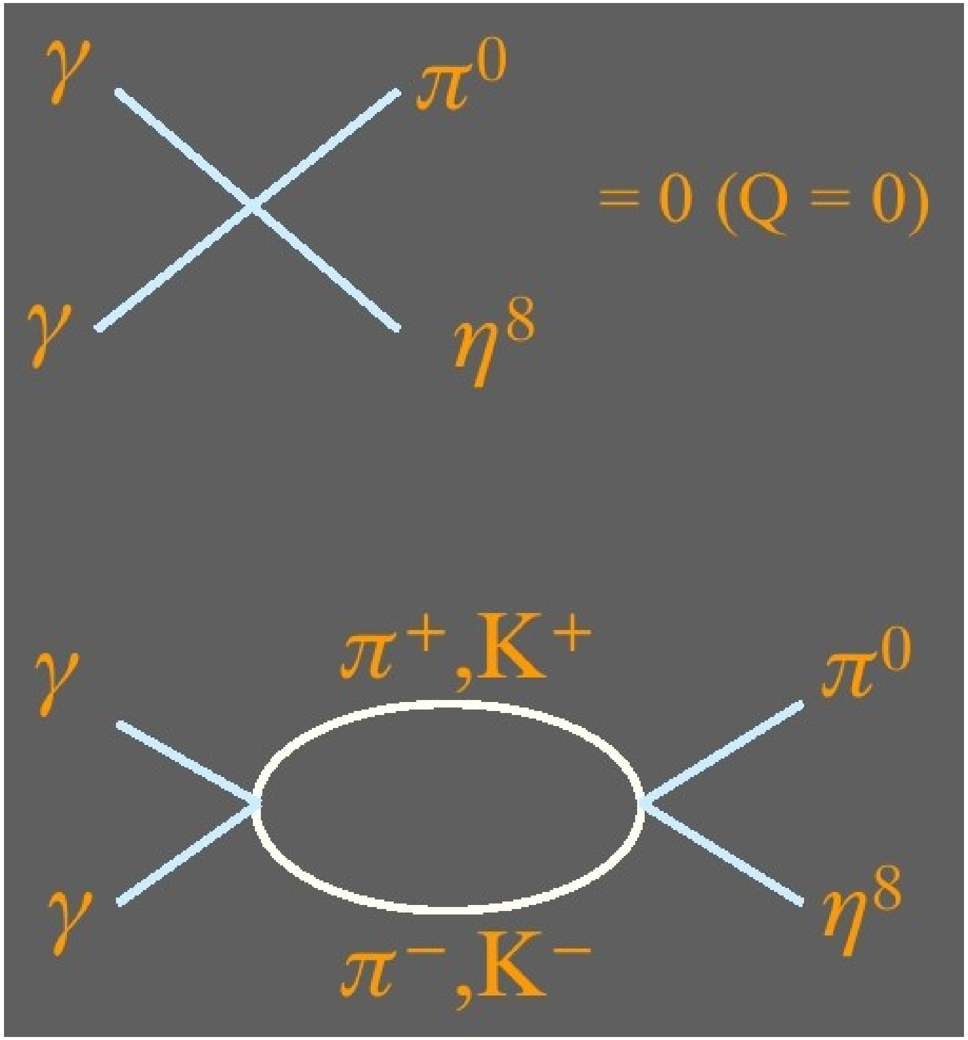
PLB 591(2004) 49



Upper limits on $\pi^+\pi^-/\gamma\gamma\gamma$,
background limited!
They can be improved by a
factor $\sqrt{(L_{NEW}/L_{OLD})} \sim 2$

$\eta \rightarrow \pi^0 \gamma\gamma$: a window on p^6 ChPT

p^2 L_2 contributions at tree level:



p^4 Coupling proportional to the charges, zero also for L_4 @ tree level.

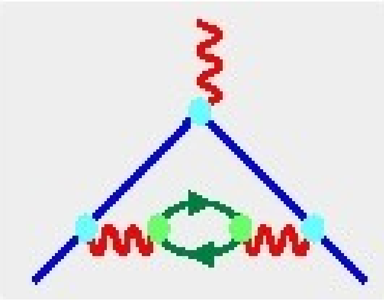
1-loop contributions from L_2 vertices, suppressed by G parity conservation and kaon mass suppression:

Br ~ 3.29×10^{-3} eV/1.18 keV = 2.8×10^{-6}

the muon anomaly

the muon anomalous magnetic moment

$$\vec{\mu} = g \frac{e\hbar}{2m} \vec{s}$$



experiment E821 at Brookhaven

$a_\mu = (g_\mu - 2)/2 = (116\ 592\ 080 \pm 60)\ 10^{-11}$

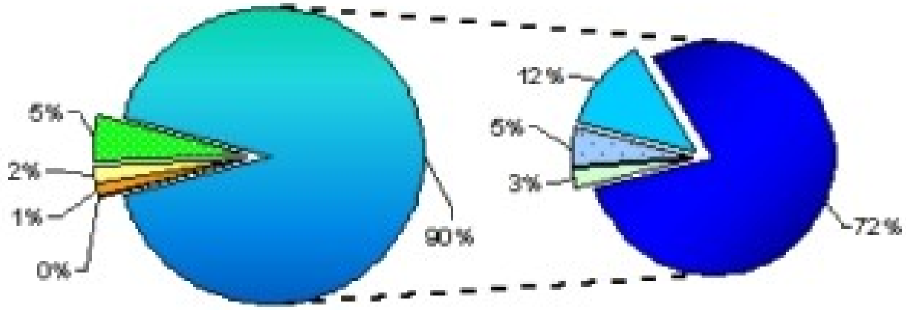
theory: $a_\mu = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had} + a_\mu^{new}$

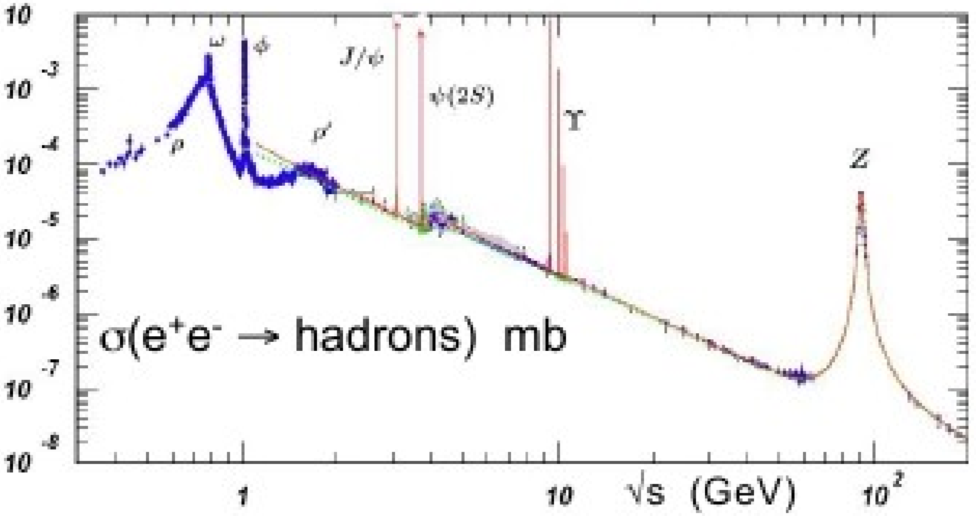
the hadronic contribution is large
$a_\mu^{had} \approx 7000 \times 10^{-11}$
and gives the largest theory error

a_μ^{had} computed with the dispersion relation

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

the kernel K(s) behaves ~ 1/s





2π	3π (+ω,φ)	4π	> 4π (+KK)	1.8 - 3.7	3.7 - 5 (+J/ψ, ψ)	5 - 12 (+Υ)	12 - ∞

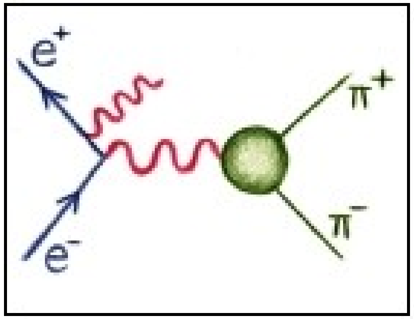
$e^+e^- \rightarrow \pi^+\pi^-\gamma$

measuring $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$

contribution to a_μ for $\sqrt{s}$ < 1 GeV ≈ **2/3**, mainly $e^+e^- \rightarrow \pi^+\pi^-$

DAΦNE is tuned at $\sqrt{s} = m_\phi$

KLOE: stay at the ϕ peak, use the ***radiative return*** method



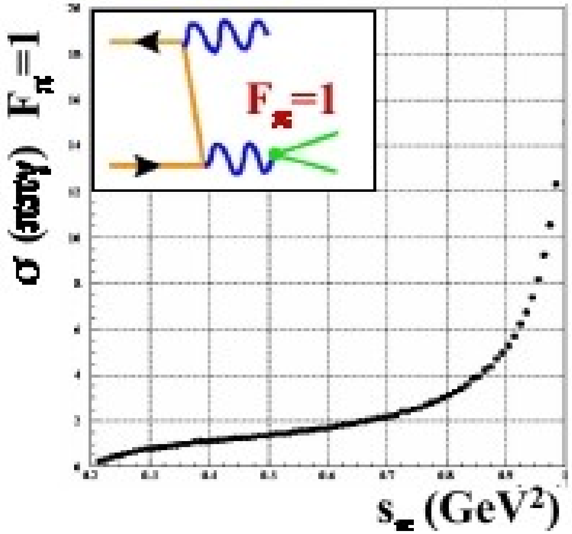
Initial State Radiation

- ***no γ tagging***: *photons* $\theta_\gamma < 15^o$ or $\theta_\gamma > 165^o$, *pions* $50^o < \theta_\pi < 130^o$
- small relative contribution of *FSR*
- reduced background contamination from $\phi \rightarrow \pi^+\pi^-\pi^0$
- measure differential cross section $e^+e^- \rightarrow \pi^+\pi^-\gamma$ as function of the $\pi\pi$ invariant mass
- extract $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ using the radiator function
- correct for final state radiation

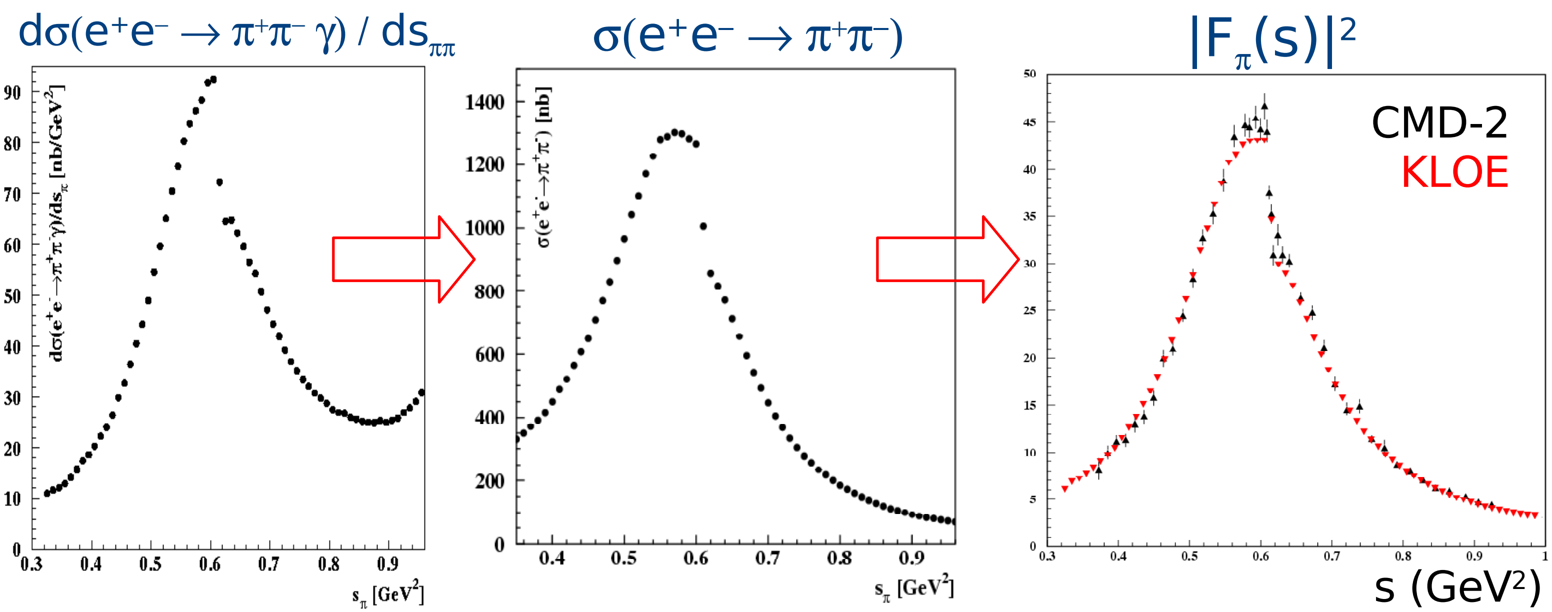
main error in $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$

$$\sigma(e^+e^- \rightarrow \pi^+\pi^-) H(m^2_{\pi\pi}, s) = m^2_{\pi\pi} \left[\frac{d\sigma(\pi^+\pi^-\gamma)}{dm^2_{\pi\pi}}\right]_{ISR}$$

PHOKARA event generator used as radiator function



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



statistical error of $\sigma(e^+e^- \to \pi^+\pi^-)$ is negligible,

systematic error is ±1.3%: 0.9% measurement $\oplus$ 0.9% from $H(s_{\pi\pi},s)$

<u>two different methods</u>: CMD-2: energy scan, KLOE: radiative return

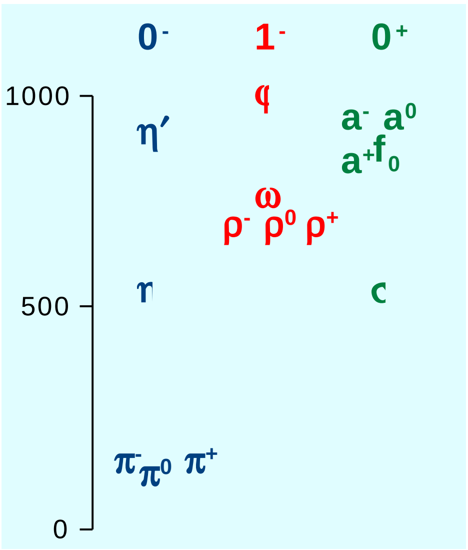
fair agreement *(but at the peak ?)*, good agreement for a_μ^{had}

KLOE: $0.35 < s < 0.95$ $\quad a_\mu^{had} = (3756 \pm 8_{stat} \pm 35_{syst} \pm 35_{\mathbf{theo}})\ 10^{-11}$

CMD-2: $0.37 < s < 0.93$ $\quad a_\mu^{had} = (3786 \pm 27_{stat} \pm 23_{syst})\ 10^{-11}$

VEPP-4M
Novosibirsks

light mesons

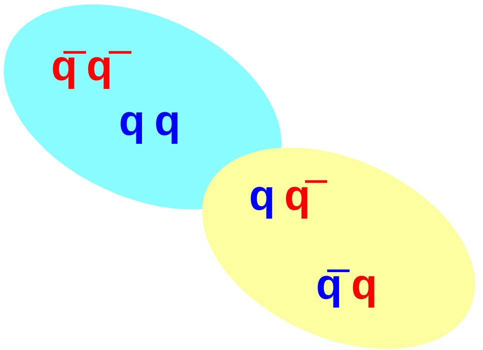


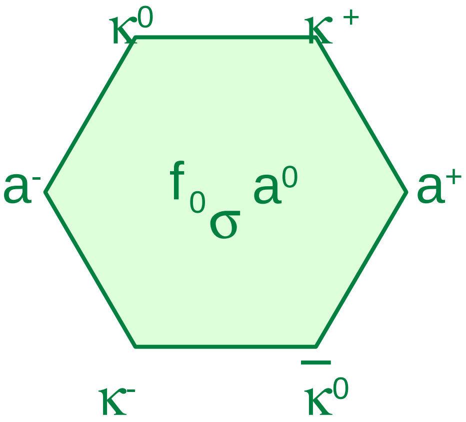
light mesons: $q\bar{q}$ pairs in the lowest state of angular momentum
antisymmetric for interchange of colour, flavour, spin
doesn't work for scalar mesons

- what is the structure of 0^+ mesons ?
- why an inverted mass spectrum ?
- do they obey the $SU(3)_{flavour}$ symmetry ?
- do κ and σ really exist ?

models

- bound state of two **diquarks**
- **molecule** of two pseudoscalar mesons





φ decays to scalar mesons, $\phi \to f_0\gamma$, $\phi \to a_0\gamma$

they are almost degenerate in mass close to the $s\bar{s}$ threshold

f_0 and a_0 should contain some hidden strangeness

σ should reveal itself in the ππγ mass spectrum

ϕ radiative decays

$1^- \rightarrow 0^-$ magnetic dipole transition $\phi \rightarrow \eta'\gamma$; $\phi \rightarrow \eta\gamma$; $\phi \rightarrow \pi^0\gamma$

$1^- \rightarrow 0^+$ electric dipole transition $\phi \rightarrow a_0\gamma$; $\phi \rightarrow f_0\gamma$; very broad resonances !

a_0 isospin $|1,0\rangle = \frac{|\pi^+\pi^-\rangle - |\pi^-\pi^+\rangle}{\sqrt{2}}$ antisymmetric, does not decay $\rightarrow \pi\pi$, but $\rightarrow \eta\pi^0$

f_0 $|0,0\rangle = \frac{|\pi^+\pi^-\rangle - |\pi^0\pi^0\rangle + |\pi^-\pi^+\rangle}{\sqrt{3}}$ decays in the three combinations with equal weight

$\phi \rightarrow a_0\gamma$ $a_0 \rightarrow \eta\pi^0$; $\eta \rightarrow \pi^+\pi^0\pi^-$ or $\gamma\gamma$; final state: 2 tracks + 5 photons OR 5 photons

- kinematic fit in the hypothesis $\eta\pi^0\gamma$,
- fit the $\eta\pi^0$ mass spectrum with the amplitude $A(\phi \rightarrow a_0\gamma) + A(\phi \rightarrow \rho^0\pi^0)$

$\phi \rightarrow f_0\gamma$ $f_0 \rightarrow \pi^0\pi^0$; final state: 5 photons

- kinematic fit in the hypothesis $\pi^0\pi^0\gamma$,
- fit the $\pi^0\pi^0$ mass spectrum with the amplitude $A(\phi \rightarrow f_0\gamma) + A(\phi \rightarrow \rho^0\pi^0) + A(\phi \rightarrow \sigma\gamma)$

$f_0 \rightarrow \pi^+\pi^-$; final state: 2 tracks + 1 photon

- large background from ISR $\rho^0 \rightarrow \pi^+\pi^-$
- fit the $\pi^+\pi^-$ mass spectrum with the amplitude $A_{IRS} + A_{FRS} + A_{cont}(\rho\pi\gamma) + A(\phi \rightarrow f_0\gamma) + A(\phi \rightarrow \sigma\gamma)$

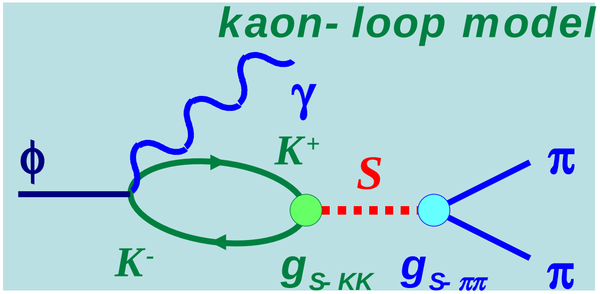
scalar mesons

results very model-dependent

$g^2_{aKK}/4\pi = 0.40 \pm 0.04\ \mathrm{GeV}^2$

$g^2_{aKK}/g^2_{a\eta\pi} = 0.55 \pm 0.07$

$BR(\phi \to a_0\gamma) = (0.74 \pm 0.07)\ 10^{-4}$



$g^2_{fKK}/4\pi = 2.79 \pm 0.12\ \mathrm{GeV}^2$

$g^2_{fKK}/g^2_{f\pi\pi} = 4.00 \pm 0.14$

$BR(\phi \to \pi^0\pi^0\gamma) = (1.07 \pm 0.07)\ 10^{-4}$

σ favoured in the fit

$g^2_{fKK}/4\pi = 2.76 \pm 0.13\ \mathrm{GeV}^2$

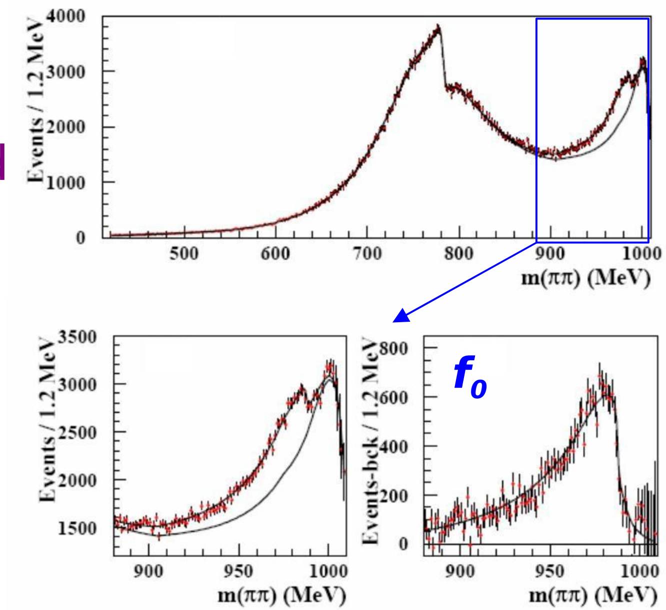
$g^2_{fKK}/g^2_{f\pi\pi} = 2.66 \pm 0.10$

$BR(\phi \to \pi^+\pi^-\gamma) = (2.1 \pm 0.4)\ 10^{-4}$

σ not needed in the fit

fit of the $\pi^+\pi^-$ mass spectrum with the kaon-loop model

- a_0 and f_0 strongly coupled to *KK*, f_0 more than a_0
- branching ratios relatively large
- no evidence for σ meson, neither excluded nor confirmed
- results consistent with the description of scalar mesons as bound states of diquarks



$$a^- = ds\ \bar{d}\bar{s} \qquad a^0 = \frac{us\ \bar{u}\bar{s} - ds\ \bar{d}\bar{s}}{\sqrt{2}} \qquad a^+ = us\ \bar{d}\bar{s}$$

$$f = \frac{us\ \bar{u}\bar{s} + ds\ \bar{d}\bar{s}}{\sqrt{2}}$$

$$\sigma = ud\ \bar{u}\bar{d}$$

pseudoscalar mesons

η–η' mixing

in the SU(3) basis

$$|\pi_8\rangle = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}} \qquad |\eta_8\rangle = \frac{u\bar{u} + d\bar{d} - 2s\bar{s}}{\sqrt{6}} \qquad |\eta_0\rangle = \frac{u\bar{u} + d\bar{d} + s\bar{s}}{\sqrt{3}}$$

who are π^0, η, η' ?

likely $\pi^0 = |\pi_8\rangle$ with no strange quark and

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos\theta_P & \sin\theta_P \\ -\sin\theta_P & \cos\theta_P \end{pmatrix} \begin{pmatrix} \eta_8 \\ \eta_0 \end{pmatrix}$$

in the flavour basis

$$|N\rangle = \frac{u\bar{u} + d\bar{d}}{\sqrt{2}} \qquad |S\rangle = s\bar{s} \qquad \varphi_P = \theta_P + \mathrm{atan}\sqrt{2}$$

measure the decays $\phi \to \eta'\gamma$ and $\phi \to \eta\gamma$ selecting the same final state

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

$$\frac{BR(\phi \to \eta'\gamma)}{BR(\phi \to \eta\gamma)} = (4.76 \pm 0.22)\ 10^{-3}$$

$$BR(\phi \to \eta'\gamma) = (6.19 \pm 0.30)\ 10^{-5}$$

flavour basis: $\varphi_P = (41.5 \pm 0.7 \pm 0.6_{theo})^o$ $\qquad$ SU(3) basis: $\theta_P = (-13.2 \pm 0.7 \pm 0.6_{theo})^o$

η forbidden decays

$\eta \to \gamma\gamma\gamma$ $\quad$ ~~C~~ $\quad$ even $\to$ odd $\quad$ $BR(\eta \to \gamma\gamma\gamma) < 1.6\ 10^{-5}$ 90% C.L.

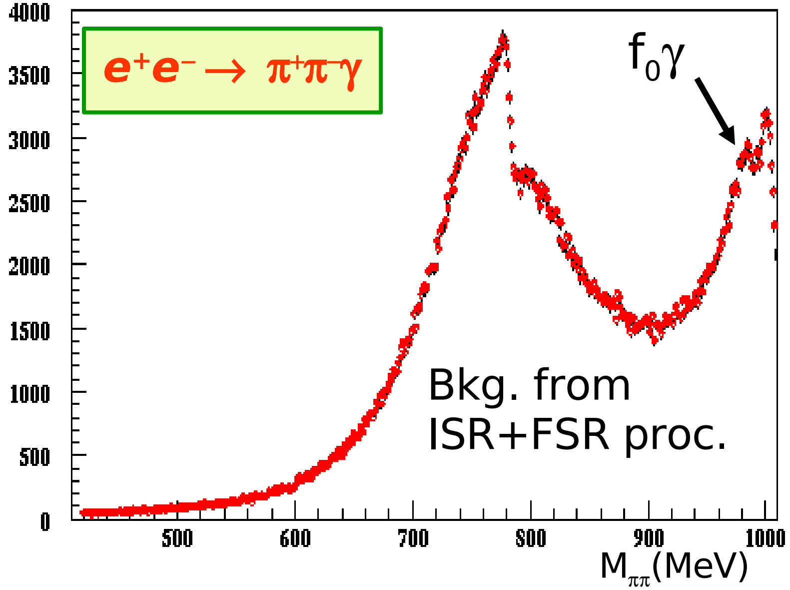
$\eta \to \pi^+\pi^-$ $\quad$ ~~P~~ and ~~CP~~ $\quad$ odd $\to$ even $\quad$ $BR(\eta \to \pi^+\pi^-) < 1.3\ 10^{-5}$ 90% C.L.

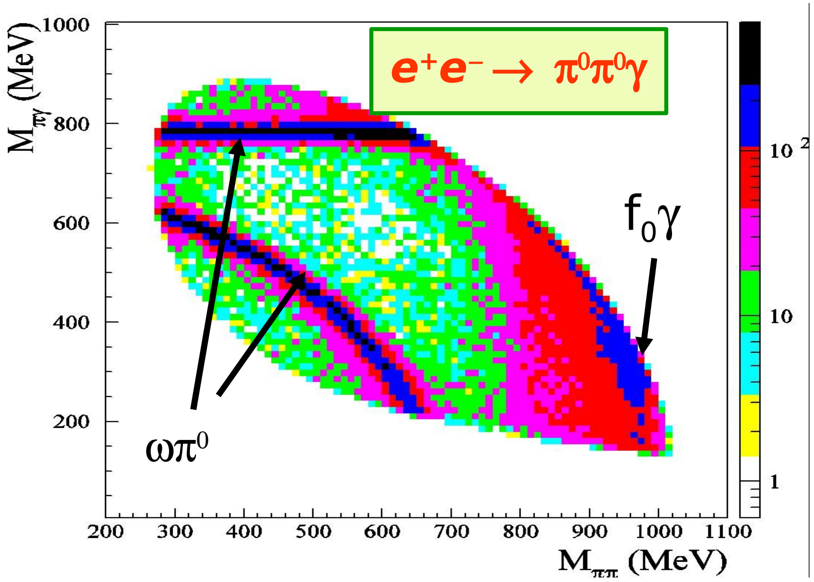
best world limits

Results on f0

KLOE has studied the $f_0(980)$ through the decay chains

$\phi \rightarrow f_0\gamma \rightarrow \pi^+\pi^-\gamma$ **PLB 634 (2006)** $\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$ **Acc. by EPJ**





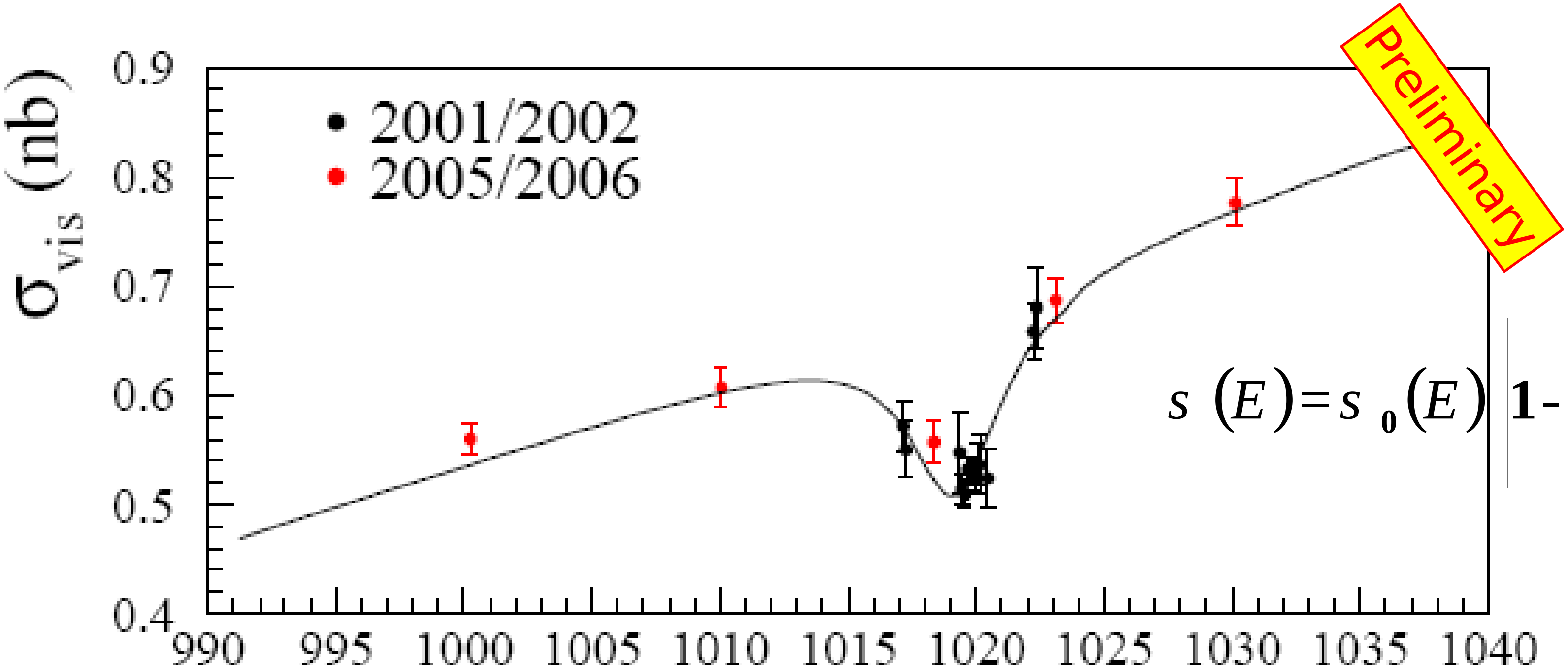
Experimental distributions have been fitted with predictions from Kaon-Loop and direct scalar coupling to vector mesons, taking into account all the contributions to the final states.

Data can be described by both the models.

To fit the $\pi^0\pi^0\gamma$ spectrum with predictions from Kaon-loop model, a $\sigma(600)$ contribution must be included. The KK coupling, in the model with direct scalar coupling to vector mesons results weaker from $\pi^0\pi^0\gamma$ analysis than in the $\pi^+\pi^-\gamma$ study.

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

KLOE can measure the inteference between the non-resonant process and the resonant ϕ decays ($\phi \to \omega\pi$ / $\rho\pi$ / $f_0\gamma$) with the same final state:



$$s(E)=s_0(E)\left|1-Z_{pg}\frac{m_f G_f}{D_f}\right|^2$$

√s (MeV)

Results of the fit (01/02):

$$\sigma_0^{\varpi\iota\sigma}=0.747 \quad 0.028^{+0.001}_{-0.015}\ \nu\beta$$

$$(Z)=0.040 \quad 0.020^{+0.009}_{-0.001}$$

$$(Z)=-0.160 \quad 0.022^{+0.001}_{-0.004}$$

Next steps:
- include 2005/2006 scan data in fit
- evaluation of systematics

What's next? KLOE2

DAΦNE will run in 2006-07 for two other experiments: SIDDHARTA and FINUDA
with periods of machine developments to increase the luminosity and the beam lifetime

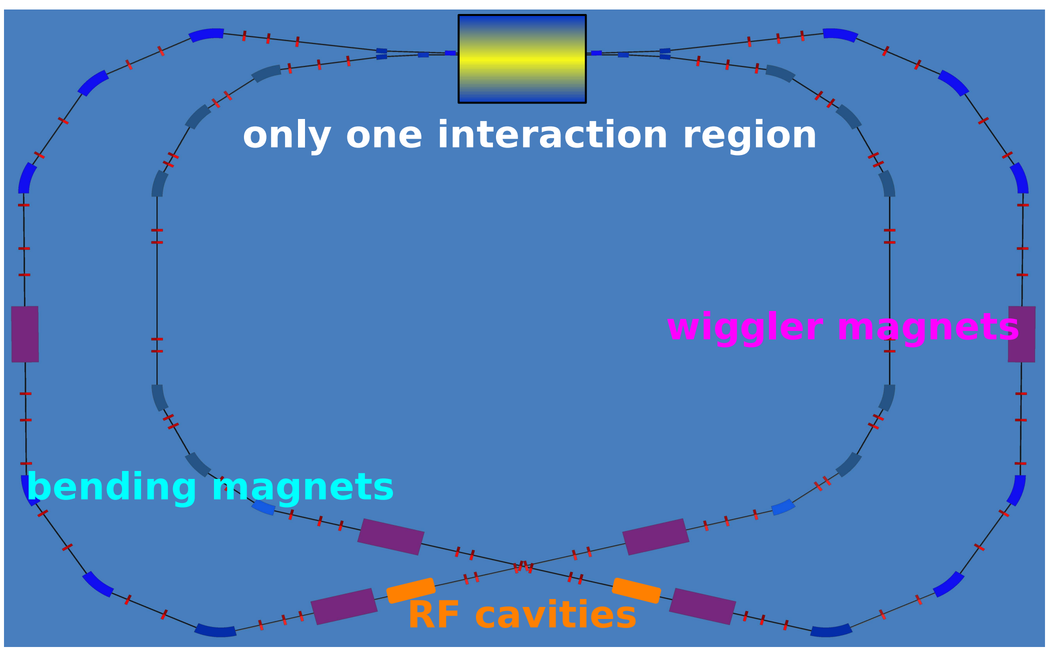
plan (*to be approved*) to start in 2008 building a DAΦNE-2

- higher luminosity at the ϕ: $\approx 8\ 10^{32}\ cm^{-2}s^{-1} \Rightarrow 10\ fb^{-1}$ per year
- maximum energy, $\sqrt{s} \approx 2.5$ GeV

and start a new physics program in ≥ 2011 to reach $\approx 40\ fb^{-1}$

⇒

$3\times10^{10}\ \phi$
2×10^{9} tagged K_S
1×10^{9} tagged K_L
$4\times10^{8}\ \eta$
…



expressions of interest presented at the Laboratory this spring:

Continuation of KLOE physics program at DAΦNE upgraded in luminosity and in energy

Measurement of the nucleon form factors in the time-like region

Study of deeply bound kaonic nuclear states at at DAΦNE-2