KLOE: Analysis news and near future expectations

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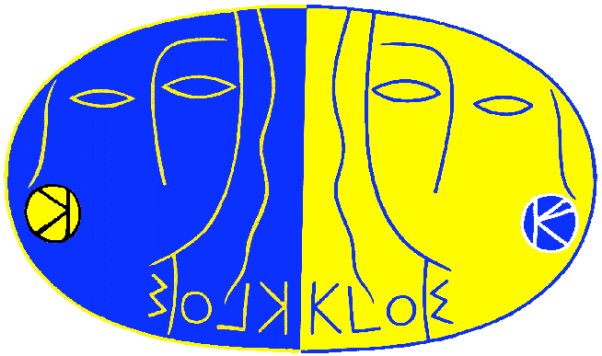
(for the KLOE collaboration)



LNF Scientific Committee

Frascati, 27-28 November 2006

MC production for 04/05 data:

- Simulation at scale 1:1 of 2004/05 data (2000 pb^{-1}).
- Simulates backgrounds and run conditions of the data taking (on run-by-run basis)
- Big work devoted to improve the MC simulation:

- Map of 2004-2005 machine energy and trigger conditions ready
- New IR geometry in simulation
- Better parameterizations of EmC response: t, E resolution; cluster efficiency
- Improved simulation of nuclear interactions in DC wall and beam pipe
- New event generators: K_S □ □$^+$□$^-e^+e^-$; □□ e□, □□ e^+e□; e^+e□ □ □□^{0}
- Simulation of dE/dx measurement in DC
- Machine background from events acquired with random trigger
- Correlated noise in charged kaon tracking

This "preparation" work ended in June 06

MC production for 04/05 data:

Status of the production

• Pre-production test on a sample of 350 pb^{-1} successfully completed.

• Real production started in August (on 214 B80 CPU).

- 800 pb^{-1} □□ *all* events (LSF 1:1) done

• Dedicated work on data throughput. We are now using 280 B80 CPU for the MC

Offline plans:

• Reprocessing of 2004 data set (□700 pb^{-1}) which were reconstructed with bad wire maps.

• We think to complete the **MC simulation of 2004/05 data and the reprocessing of 2004** data by May 2007

Recent Kaon analysis:

$K_S K_L \to \pi^+\pi^-\pi^+\pi^-$	Quantum Interference	**PLB 642 (2006) 315**	
CP and CPT violation	Bell-Steinberger rel. + KLOE data	**Accepted by JHEP**	
$K_S \to \pi^0\pi^0\pi^0$	UL on BR at 10^{-7}	**PLB 619 (2005) 61**	**PDG06**
$K_S \to \pi e \nu$	BR to 1.3%, form factor slope, charge asymmetry	**PLB 636 (2006) 173**	**PDG06**
$K_S \to \pi^+\pi^-$, $\pi^0\pi^0$	$\Gamma(\pi^+\pi^-)/\Gamma(\pi^0\pi^0)$ to ~0.25%	**Accepted by EPJC**	**PDG06**
$K_L \to \pi l \nu$, $\pi\pi\pi$	Absolute BR's to ~ 0.5% K_L lifetime from Σ(BR)=1	**PLB 632 (2006) 43**	**PDG06**
K_L lifetime	from $K_L \to \pi^0\pi^0\pi^0$ to ~ 0.5%	**PLB 626 (2005) 15**	**PDG06**
$K_L \to \pi e \nu$	Form factor slopes	**PLB 636 (2006) 166**	**PDG06**
$K_L \to \pi e \nu \gamma$	BR to ~ 2 %	**Preliminary**	
$K_L \to \pi^+\pi^-$	BR to 1.1%	**PLB 638 (2006) 140**	**PDG06**
$K_L \to \gamma\gamma$	$\Gamma(\gamma\gamma)/\Gamma(\pi^0\pi^0\pi^0)$ to 1.1%	**PLB 566 (2003) 61**	
$K^+ \to \pi^+\pi^0\pi^0$	BR to 1.4%	**PLB 597 (2004) 139**	
$K^+ \to \pi^+\gamma$	Absolute BR to ~ 0.27%	**PLB 632 (2006) 76**	**PDG06**
$K^\pm \to \pi^0 l^\pm \nu$	Absolute BR's to ~ 1.5%	**Preliminary**	
$K^\pm$ lifetime	two independent measurements	**Preliminary**	
etc…			

V_{us} from semileptonic decays:

Unitarity of the CKM quark mixing matrix (or lack thereof) allows to test for the existence of new physics not described by the Standard Model.

Unitarity condition from 1st row:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 \; \square \; |V_{ud}|^2 + |V_{us}|^2 \equiv 1 \; \square \; \square$$

$|V_{ud}|$ from superallowed $0^+ \rightarrow 0^+$ beta decays

$|V_{ud}| = 0.97377(27)$ (Marciano, Sirlin 2006)

One can extract $|f_+(0)\cdot V_{us}|^2$ from K semileptonic decays via

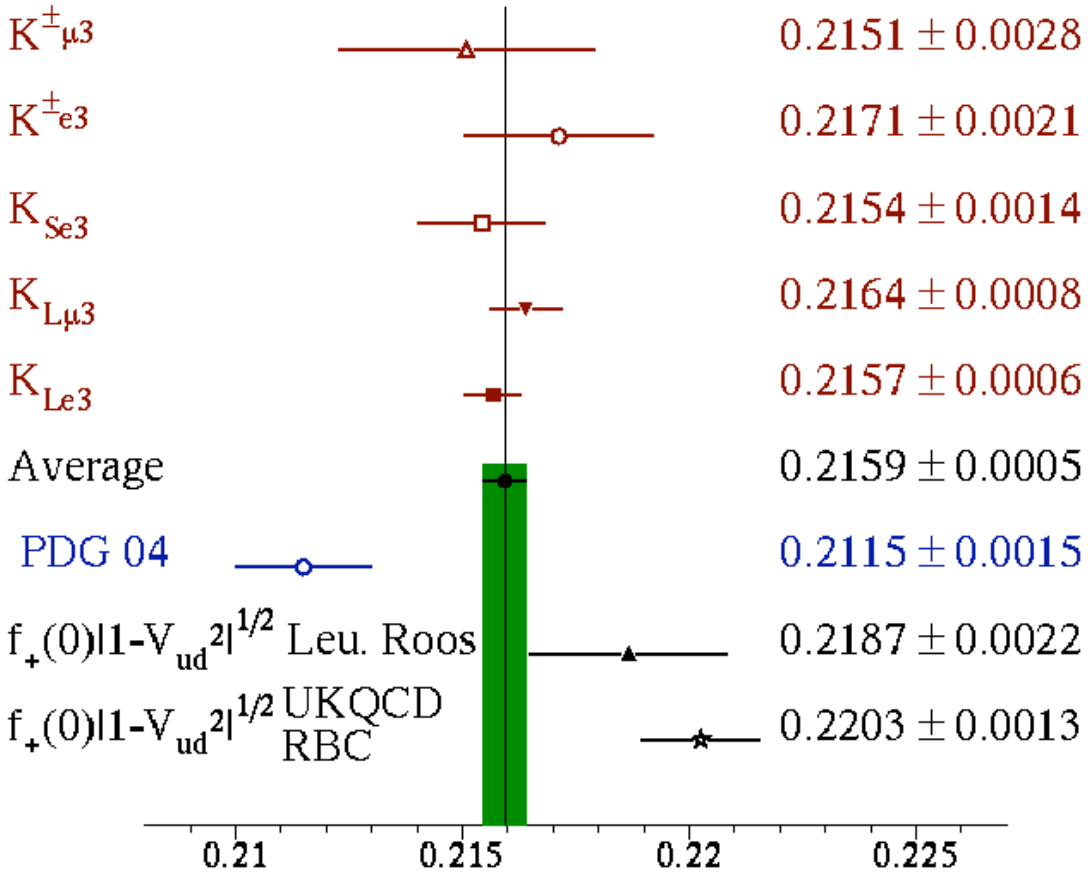
$$\square(K\square \; \square l \square(\square)) \; \mu \; |f_+(0)\cdot V_{us}|^2 \; I(\square_+) \; (1 + \square I(\square_+)/2 + \square_{\square\square})^2 \cdot S_{ew}$$

Measurement — $V_{us}\cdot$ form factor — Slope factor — rad. corrections

$I(\square_+)$ is the integral of the phase space density after factorizing out $f_+(0)$ and radiative corrections. $\square_+$ describes the dependence of the vector and scalar form factor on momentum transferred t (slopes $\square_+$, $\square\square_+$).

V_{us} from semileptonic decays :

KLOE results for $f_+(0)|V_{us}|$:



Slopes used in the evaluation:

λ'_+ = 0.02542(31)
λ''_+ = 0.00129(3)
(Pole model: KLOE, KTeV and NA48 av.)

λ_0 = 0.01587(95)
(KTeV and ISTRA+ av.)

Parameters for V_{US} from Unitarity:

V_{ud} = 0.97377(27)
(Marciano, Sirlin 2006)

$f_+(0)$ = 0.9610(80)
(Leutwyler, Roos 1984)

$f_+(0)$ = 0.9680(16)
(UKQCD/RBC coll. 2006)

V_{us} - V_{ud} plane from $K_{\mu 2}$:

Using **BR($K^+ \to \mu^+\nu$)** from KLOE and **f_K / f_π=1.208(2)($^{+7}_{-14}$)** from MILC Coll. (2006) one can obtain **V_{us}/V_{ud} = 0.2286($^{+20}_{-11}$)** from

$$\frac{\Gamma(K \to \mu\nu_\mu(\gamma))}{\Gamma(\pi \to \mu\nu_\mu(\gamma))} \propto \frac{|V_{us}|^2 f_K^2}{|V_{ud}|^2 f_\pi^2}$$

[Marciano 2006]

Fit with V_{us}, V_{ud} from prev. Slides:

V_{us} = 0.2246($^{+9}_{-13}$)

V_{ud} = 0.97377(27)

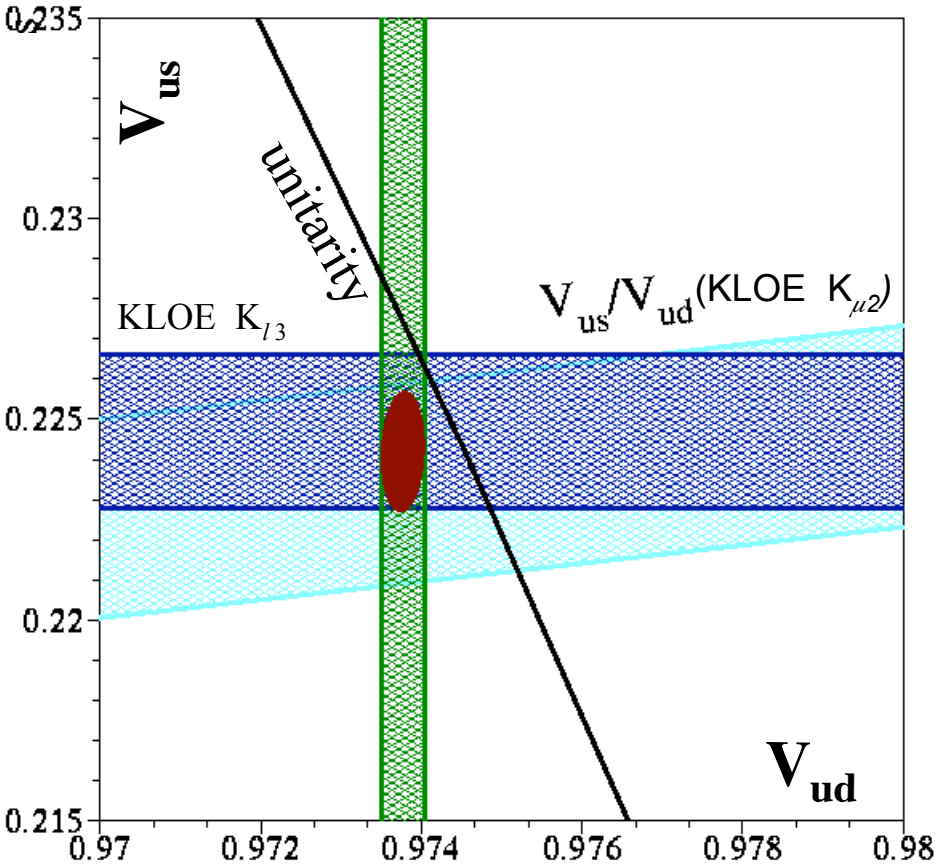
χ^2/dof = 0.046/2 P(χ^2) = 0.97

Fit with V_{us}, V_{ud} + unitarity:

V_{us} = 0.2257(7)

V_{ud} = 0.97420(16)

χ^2/dof = 3.94/1 P(χ^2) = 0.05



CPT tests using unitarity:

Exploiting unitarity in the kaon system allows to write

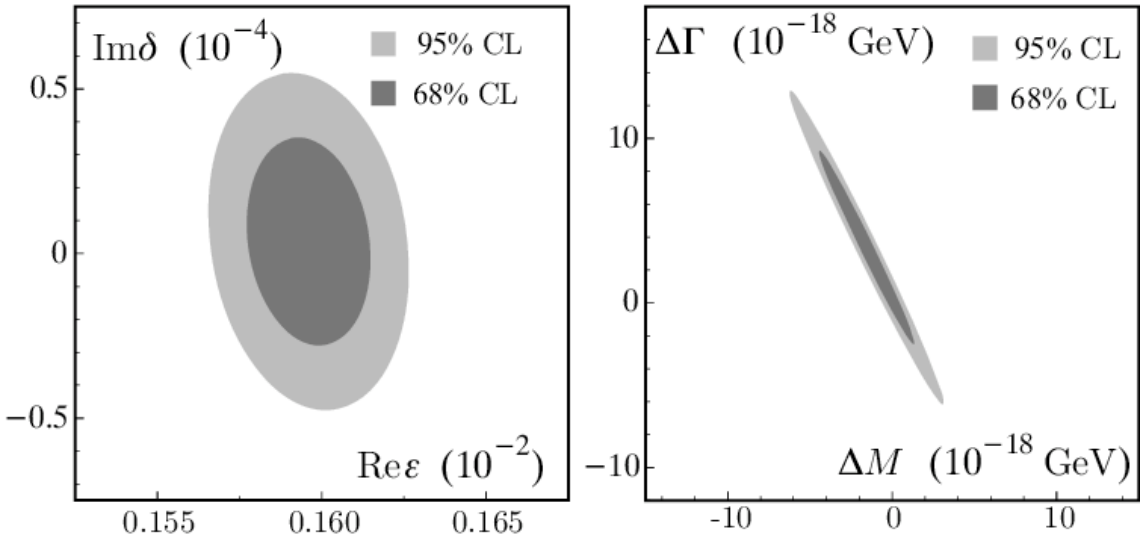
$$\frac{\eta_S + \eta_L}{\eta_S - \eta_L} + i\tan\phi_{SW}\left[\frac{e(\delta)}{1+|\delta|^2} - i\,Im(\delta)\right] = \frac{1}{\Gamma_S - \Gamma_L}\sum_f A_L(f)A_S^*(f)$$

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

Final results using KLOE data:
(Article has been accepted by JHEP)

Re ε = (159.6 ± 1.3) $\cdot 10^{-5}$
Im δ = (0.4 ± 2.1) $\cdot 10^{-5}$

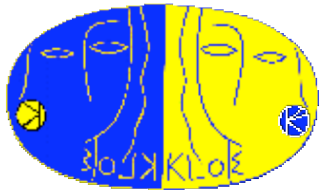
Limits on $\Delta m = (m_{K_0} - m_{\overline{K}_0})$ and $\Delta\Gamma = (\Gamma_{K_0} - \Gamma_{\overline{K}_0})$ from Imδ and Reδ



assuming CPT violation only in the mass matrix ($\Delta\Gamma$ = 0):

$|m_{K0} - m_{\overline{K0}}| < 6.3 \cdot 10^{-19}$ GeV @ 95%CL

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



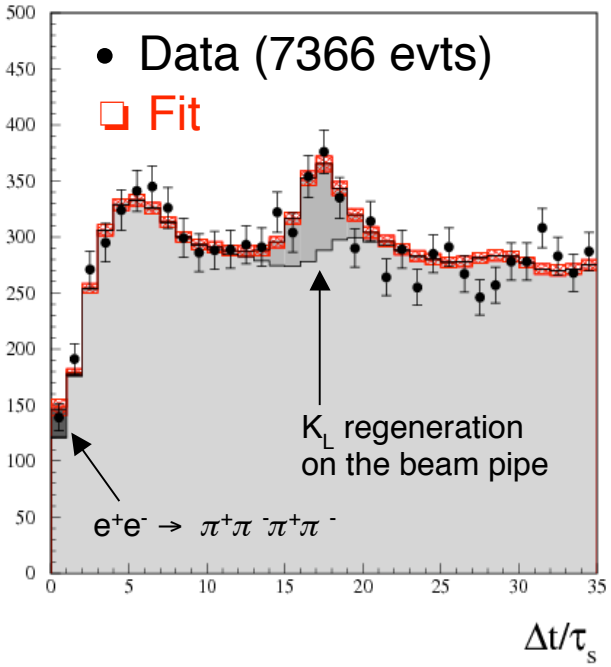
- Quantum Interference in $K_S K_L \to \pi^+\pi^-\pi^+\pi^-$:

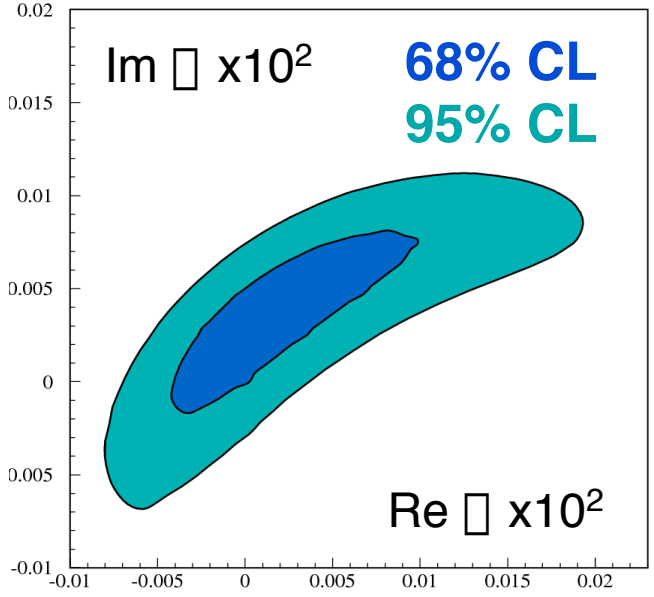
$$I(t_1, t_2, \pm) \propto e^{-\Gamma_L t_1 - \Gamma_S t_2} + e^{-\Gamma_S t_1 - \Gamma_L t_2} \mp 2(1 - |\varepsilon|) e^{-(\Gamma_S + \Gamma_L)(t_1 + t_2)/2} \cos(\Delta m \Delta t)$$

Decoherence parameter $\zeta \neq 0$ ↔ Violation of Quantum Mechanics

- Admixture of small C-even component in the initial state:

$$|i\rangle \propto (K_S K_L - K_L K_S) + \omega (K_S K_S - K_L K_L) \qquad \omega = |\omega| e^{i\phi}$$





Fit results:

δ_{SL} =
$0.018 \pm 0.040 \pm 0.007$

δ_{00} =
$(0.10 \pm 0.21 \pm 0.04) \cdot 10^{-5}$

$e\phi$ =
$(1.1^{+8.7}_{-5.3} \pm 0.9) \cdot 10^{-4}$

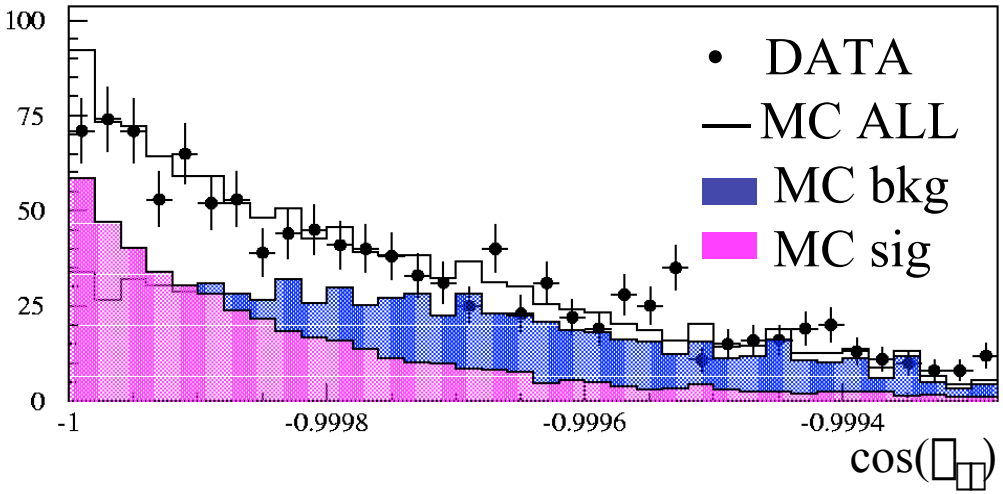
Δm =
$(3.4^{+4.8}_{-5.0} \pm 0.6) \cdot 10^{-4}$

K_S □ □□

Test of O(p^6) ChPT correction (BR(K_S □ $\gamma\gamma$) = 2.1 X 10^6 at O(p^4) ChPT)

- Tag K_S with K_L interacting in Calorimeter → pure K_S beam
- Main background: K_S □ 2□^{0} with two lost photons

N_{signal} = 607 ± 40 events
(from 1.7 pb^{-1})

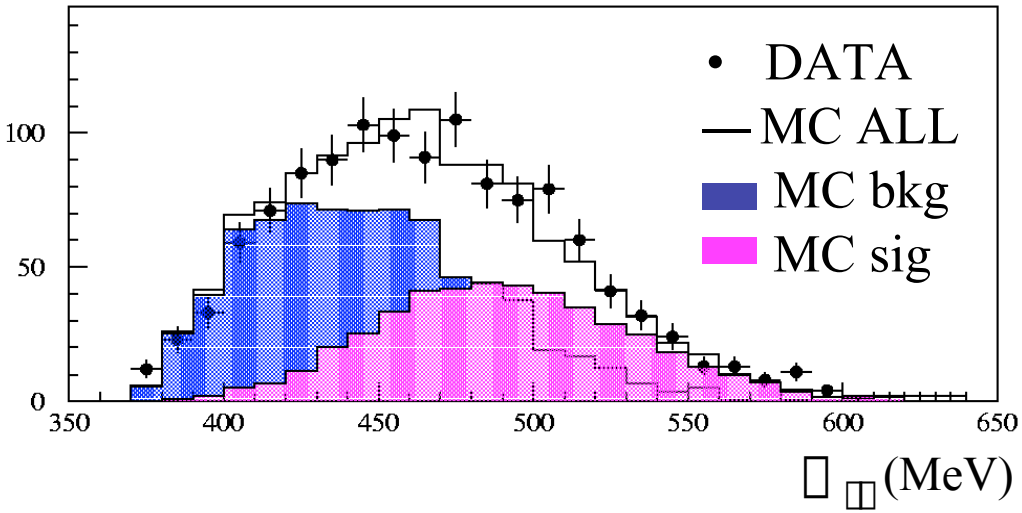


Expected statistical precision of 5%

KLOE result can confirm or disprove result from NA48:

BR(K_S □ $\gamma\gamma$) = 2.78(6)(4) X 10^6

PLB 551 (2003)



K_L □ □e□□

Test of ChPT at O(p^6) [Gasser et al. 2005]

Observable:

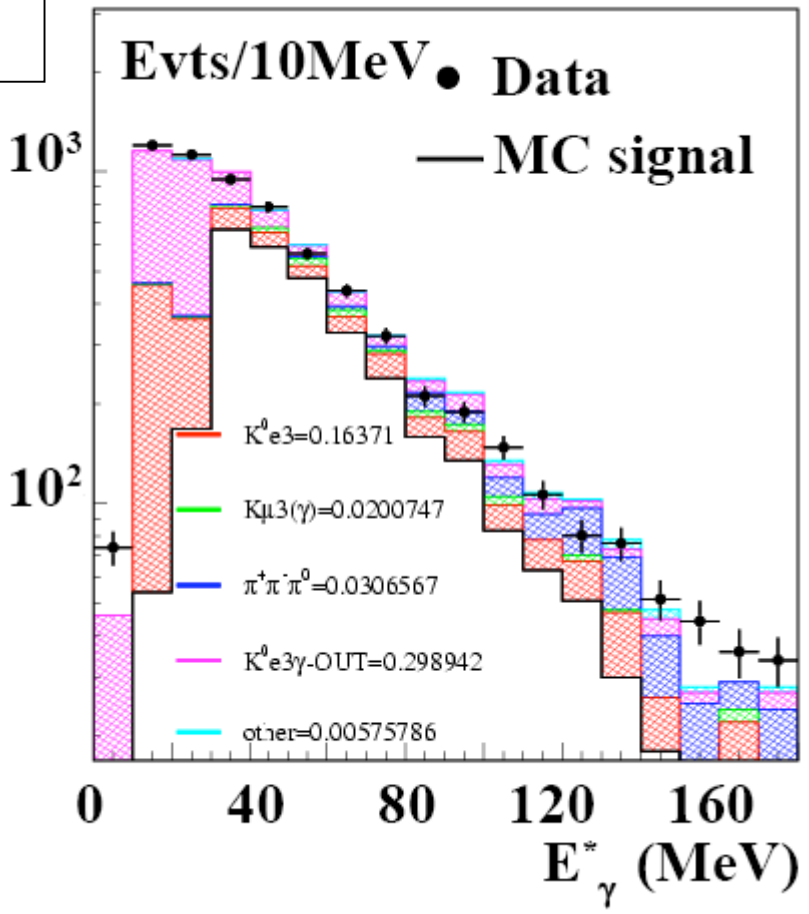
$$R = \frac{BR(K_L \to \square e \square\square;\ E_\square > 30\ MeV;\ \theta_{Lep-\square} > 20^0)}{BR(K_L \to \square e \square(\square))}$$

- Reduced syst. effects in the ratio
- Selection of inclusive sample:
  - 328pb^{-1} from 2001/2002 data
  - ~2E6 K_{e3}
- Selection of radiative subsample
  - ~6E3 signal events

Preliminary KLOE results:

$$R = 0.92 \pm 0.02_{stat} \pm 0.02_{sys}$$

- Systematics under evaluation



Kaon Physics Summary:

- Many K_S-K_L decay channels have been measured with precision ~ 1% or better
- Best limit on $K_S \to \pi^0\pi^0\pi^0$
- K_S-K_L interferometry
- First measurement of K_S semileptonic charge asymmetry

Recent results

- Close to final results for K charged semileptonic
- BR($K_L \to \pi e\nu$) with E_π>30 MeV
- Scalar form factor f_0 of $K_L \to \pi\pi\pi$ decay
- First measurement of $K_S \to \pi\pi\pi$
- Measurement of BR($K_S \to \pi\pi$)
- Measurement of BR($K^\pm \to \pi^\pm\pi^0$)

Advanced status

- Measurement of BR($K_S \to \pi^+\pi^-\pi^0$), BR($K_S \to \pi^+\pi^-e^+e^-$)
- Improve on UL($K_S \to \pi^0\pi^0\pi^0$), UL($K_S \to e^+e^-$)
- Improve on semileptonic BRs, lifetimes and form factors
- BR($K_L \to \pi\pi$) to few 10^{-3}
- $\Gamma(K^\pm \to e^\pm\nu)/\Gamma(K^\pm \to \mu^\pm\nu)$ to few 10^{-2}
- …

2.5 fb^{-1}

Hadronic Physics:

$\phi \to \pi^+\pi^-\pi^0$	Dalitz plot analysis	**PLB 561(2003) 65**
$\phi \to f_0\gamma \to \pi^+\pi^-\gamma$	f_0 coupling to $\pi\pi$, $\eta\eta$, KK	**PLB 634(2006) 148**
$\phi \to f_0\gamma \to \pi^0\pi^0\gamma$	BR($\phi \to \pi^0\pi^0\gamma$) to 5%	**PLB 537(2002) 21**
	Dalitz plot analysis, stat/syst improvements	**accepted by EPJ**
$\phi \to \eta\pi^0 \to \pi^0\pi^0\gamma$	Dependence of σ_{vis} on $\sqrt{s}$	**Preliminary**
$\phi \to \eta\,\pi^0\,\gamma$	BR($\phi \to a_0(980)\,\gamma$) to 10%	**PLB 536(2002) 209**
	stat/syst improvements	**Preliminary**
$\phi \to \eta'\,\gamma\,(\eta\,\gamma)$	$\Gamma(\phi \to \eta'\gamma)/\Gamma(\phi \to \eta\,\gamma)$ to 12%, mixing angle to 5%	**PLB 541(2002) 45**
	stat/syst improvements	**Preliminary**
$\phi \to \eta\pi\pi$	η mass measurement	**Preliminary**
$\phi \to \eta\pi^+\pi^-\pi^0$	η mass measurement, Dalitz plot analysis	**Preliminary**
$\phi \to \eta\pi^0\pi^0\pi^0$	Dalitz plot analysis	**Preliminary**
$\phi \to \eta\,\pi^0\,\eta\eta$	BR, $m_{\eta\eta}$ spectrum	**Preliminary**
$\phi \to \eta\pi^+\pi^-$	UL on BR at 10^{-5}	**PLB 606(2005) 276**
$\phi \to \eta\eta\eta$	UL on BR at 10^{-5}	**PLB 591(2004) 49**
$e^+e^- \to \pi^+\pi^-\,\gamma$	$a_{\mu\,\mathrm{had}}$ ($0.35<s_\pi<0.95$ GeV^2) to ~ 1%	**PLB 606(2005) 12**
	$a_{\mu\,\mathrm{had}}$ down to threshold, $\mu\mu\gamma$ normalization	**Preliminary**
$e^+e^- \to e^+e^-\,(\pi^+\pi^-)$	$\Gamma_{\mathrm{lept}}(\phi)$ to 1.5% and lepton universality test	**PLB 608(2005) 199**
etc…		

Br(□□ □□)/Br(□□ □□)

Final Result:

KLOE Note and draft written

$$R = \frac{BR(\square\square\ \square\square)}{BR(\square\square\ \square\square)} = (4.79 \pm 0.09_{stat} \pm 0.20_{sys}) \cdot 10^{-3}$$

$$BR(\square\square\ \square\square) = (6.24 \pm 0.12 \pm 0.28) \cdot 10^{-5}$$

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

Using the approach by Bramon et al. [Eur. Phys. J. C7, 271(1999)] and introducing a possible gluonium content via $\cos^2\phi_G$ one can extract the □-□' mixing angle $\square_P$:

$$R_{\square} = \cot^2 \square_P \cdot \cos^2 \square_G \left(1 - \frac{m_s}{\bar{m}} \cdot \frac{C_{NS}}{C_S} \cdot \frac{\tan \square_V}{\sin 2\square_P}\right)^2 \cdot \left(\frac{p_{\square\square}}{p_{\square}}\right)^3$$

KLOE prelim.

$$\square_P = (39.7 \pm 0.7_{tot})^0$$

$$|\square_G| = (22 \pm 3)^0$$

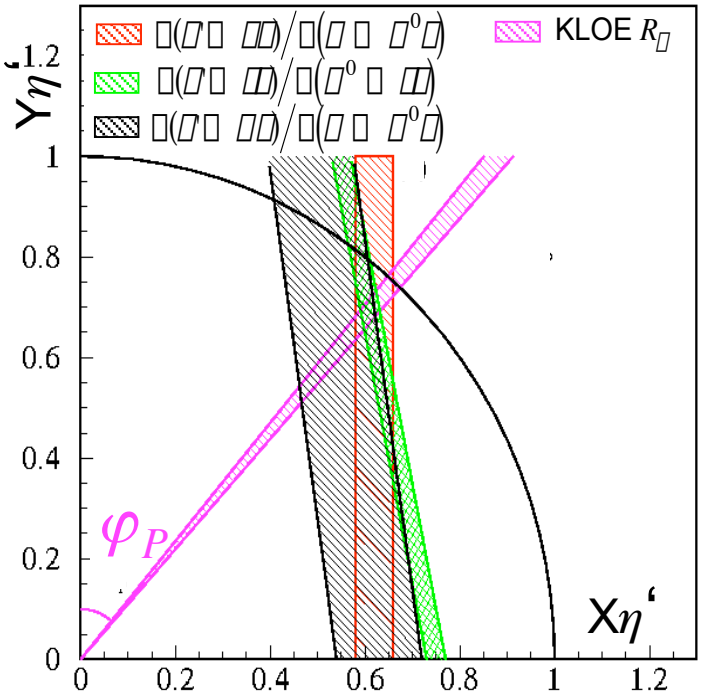
Combined analysis to evaluate possible gluonium content of □'
(4 constraints in X-Y-plane)

$$|\square\square\rangle = X \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle + Y |s\bar{s}\rangle + Z |glue\rangle$$

$$X^2 + Y^2 + Z^2 = 1$$

KLOE prelim.

$$Z^2 = 0.14 \pm 0.04$$

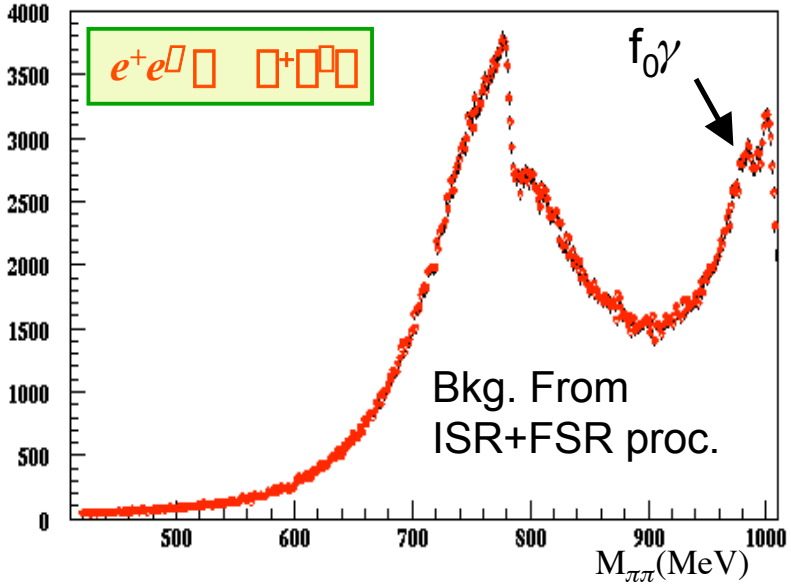


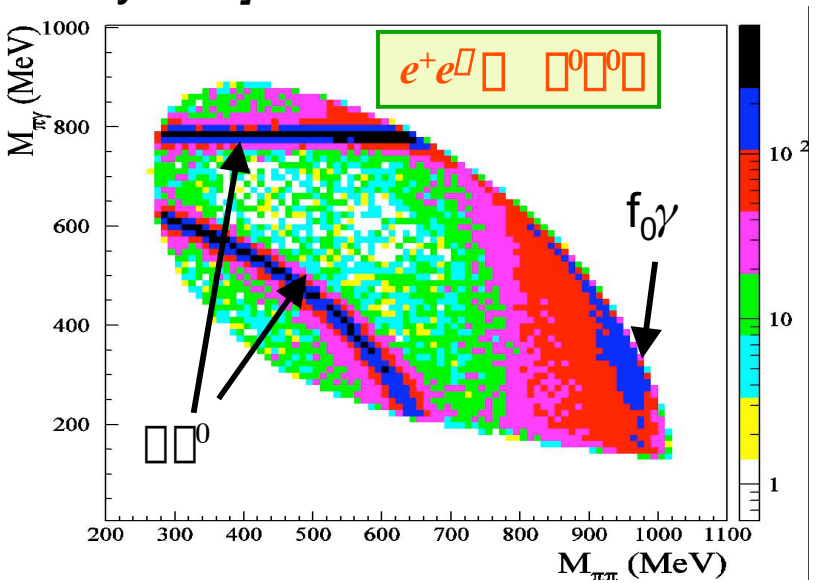
Results on $f_0(980)$:

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]*





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.

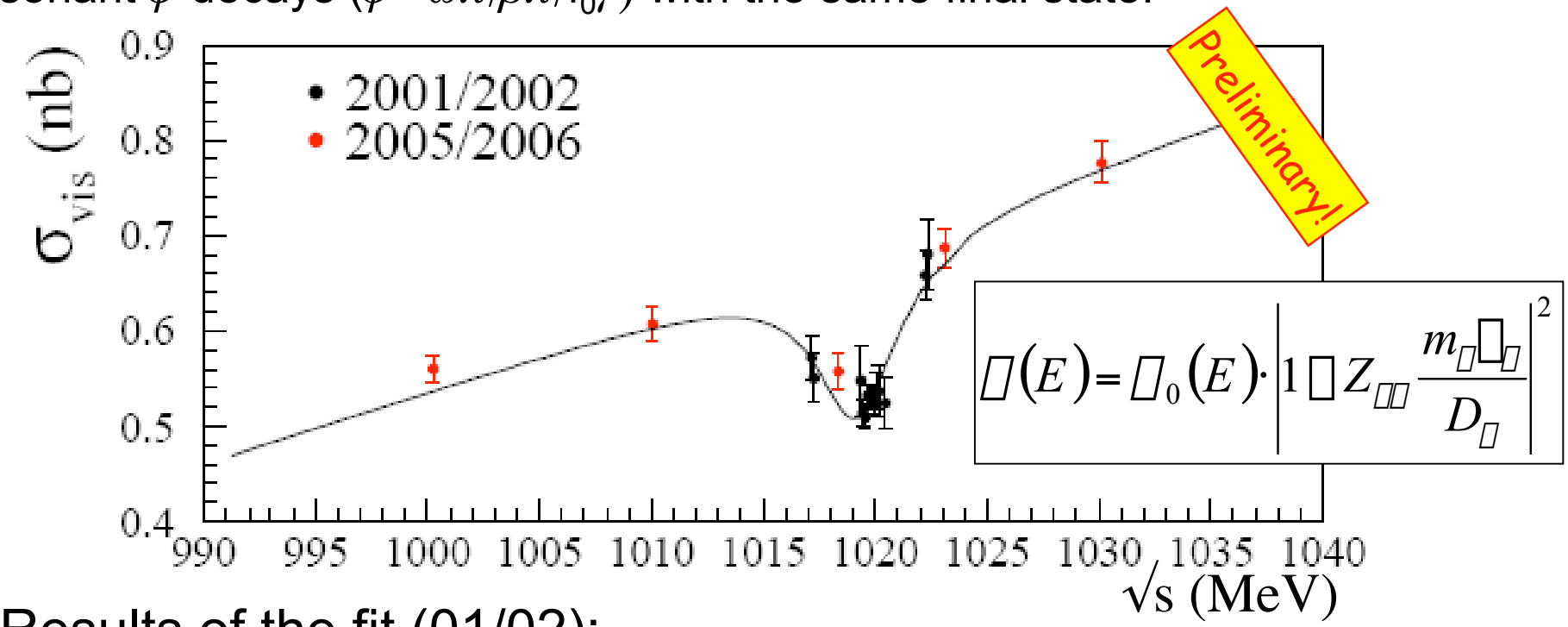
Data can be described by both the models.

To fit the $\pi^0\pi^0\gamma$ spectrum with predictions from Kaon-loop model, a σ(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.

Outlook: Combined fit to charged and neutral final states

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

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:



Results of the fit (01/02):

$$\sigma_0^{vis} = 0.747 \pm 0.028^{+0.001}_{-0.015}\ nb$$

$$|Z| = 0.040 \pm 0.020^{+0.009}_{-0.001}$$

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

Next steps:

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

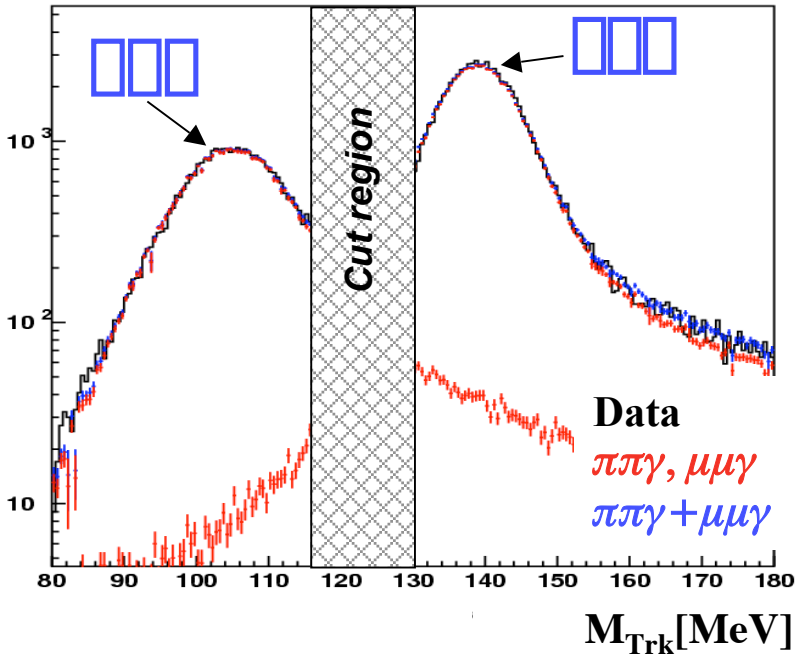
Measurement of $d\sigma_{\pi\pi\gamma}/dM_{\pi\pi}^2$:

A new analysis is carried out at small photon angles using 2002 data (240pb^{-1}) with improved machine background and calibration conditions. This alone should allow for a reduction of the total systematic error on $\sigma_{\pi\pi}$ to <1%.

In addition, one can extract $\sigma(e^+e^- \to \pi^+\pi^-)$ by performing a normalization with muon events:

$$\sigma_{\pi\pi}^{Born}(s) = \frac{d\sigma_{\pi\pi\gamma}^{obs}/ds}{d\sigma_{\mu\mu\gamma}^{obs}/ds}\sigma_{\mu\mu}^{Born}(s)$$

- many effects cancel in the ratio:
  - Vacuum Polarisation
  - Luminosity
  - Radiator function
- Pions and muons are separated by a cut in the *trackmass* variable
- Selection of muons has to have similar precision as pion selection
- Comparing $\mu\mu\gamma$-yield in data with Monte-Carlo simulation allows cross check of radiative corrections in MC!



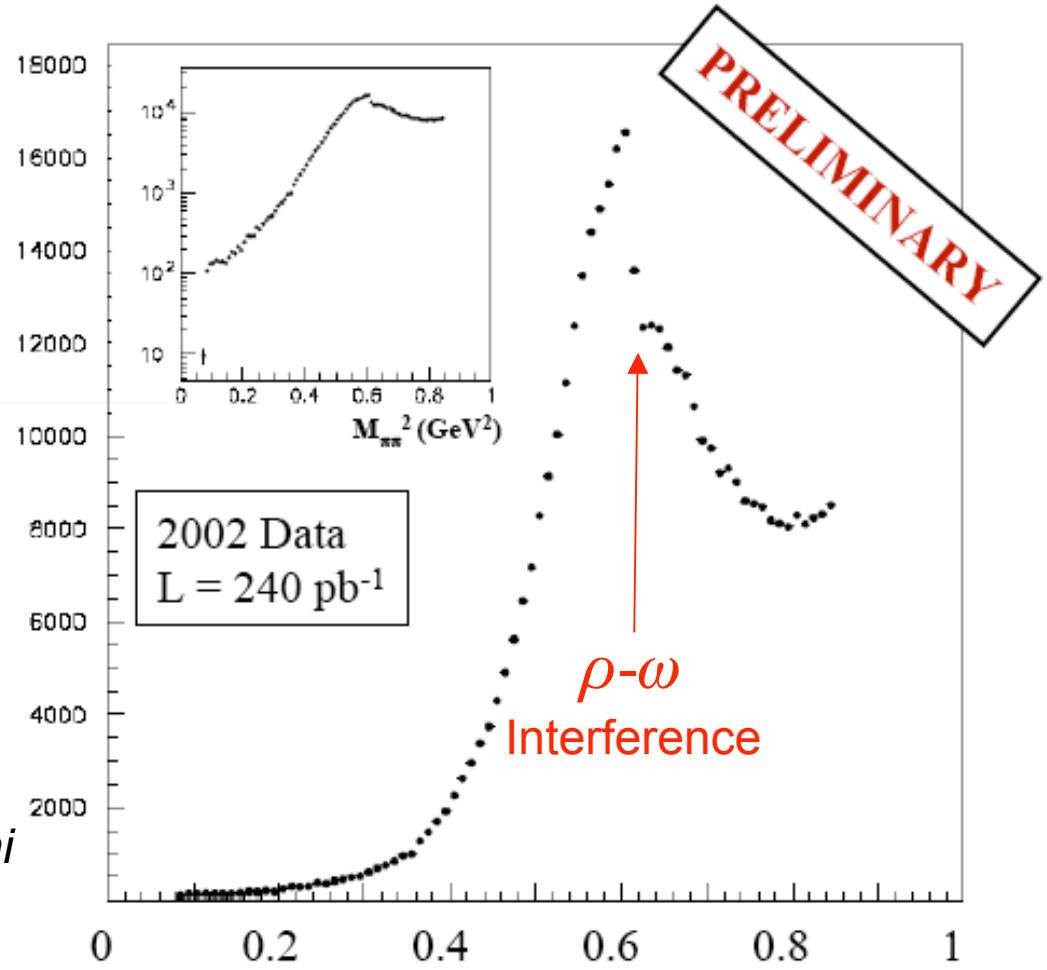
Measurement of $d\Gamma_{\pi\pi\gamma}/dM_{\pi\pi}^2$:

Analysis with photons detected at large angle allows to access the 2-pion-threshold region.

- Analysis is well advanced, evaluation of efficiencies and reducible background is finished.

- Main limitation is caused by the contribution from model dependent effects of ϕ decays ($\phi \to f_0 \gamma$, $\phi \to \rho\pi$) and Final State Radiation from pions.

- Estimate these effects from MC:
  - *PHOKHARA [EPJ C47(2006) 617]*
  - *Pancheri/Shekhovtsova/Venanzoni [PLB 642 (2006) 342]*



- *„Working Group on Rad. Corr. And MC Generators for Low Energy"*
  1st Meeting held in Frascati, Oct.16-17 2006

Hadron Physics Summary:

- □(□→ □'□)/ □ (□→ □ □) **with precision of 4%**
- Extensive study of $f_0(980)$ properties
  - via □□ f_0□□ □$^+$ □$^-$□process both in □$^+$ □$^-$ invariant mass and in the forward-backward asymmetry
  - Dalitz plot analysis in the □^{0} □^{0} final state

Recent results

- **Improved measurement for** □$_{□□}$
  - Large-Angle Photon analysis
  - Normalisation with $\mu\mu\gamma$ events
- □ mass measurement
- **Dalitz Plot of** □ → □□□
- **Upper Limit for BR(**□ → □^{0}□^{0}**)**
- **Study of** $a_0(980)$

advanced status

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

Off-Peak Data

- **Combined fit of both charged and neutral** □□□**final states and searches for** $f_0/a_0\to KK$
- **Single and Double Dalitz** □ **decays,** □ □ □^{0}□□, □□**decays**
- **etc.**

2.5 fb^{-1}

Conclusions:

- End of KLOE data taking and Roll-Out of the detector in May 2006 do not mean the end of KLOE activities

- Many analysis are in progress, a considerable amount of them is in an advanced state and close to publication

- Computing farms are busier than ever producing 2004/2005 MC samples

We are now harvesting the fruits from (almost) 6 years of KLOE data taking!

The Fruits: