KLOE results at the Frascati ϕ-factory DAΦNE

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"Meson-Nucleon Physics and the Structure of the Nucleon"

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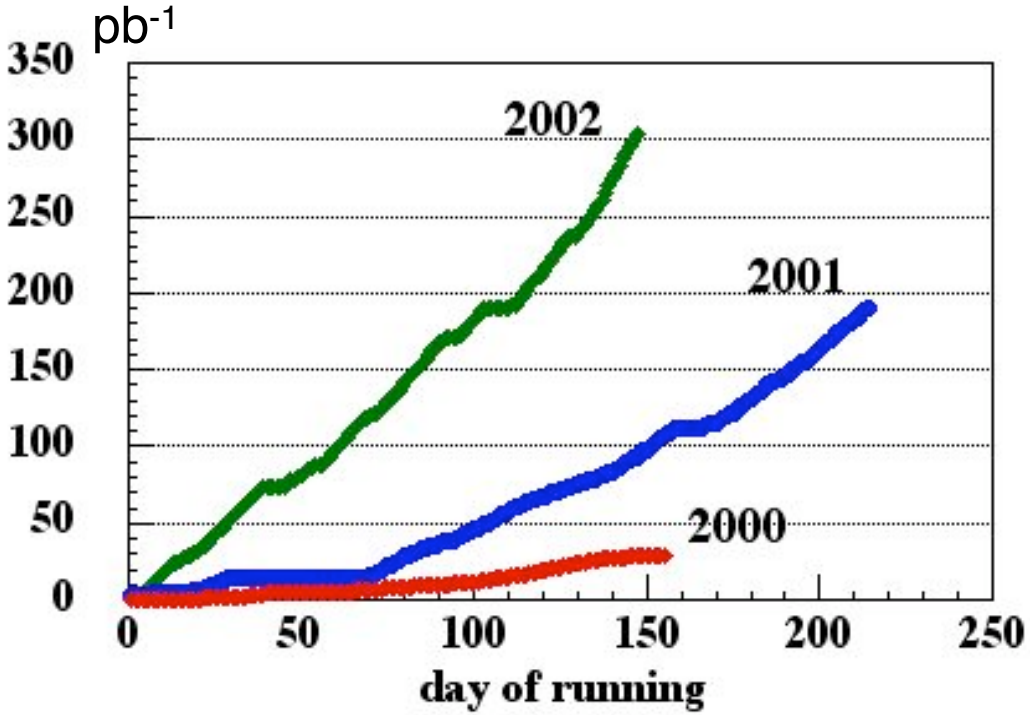
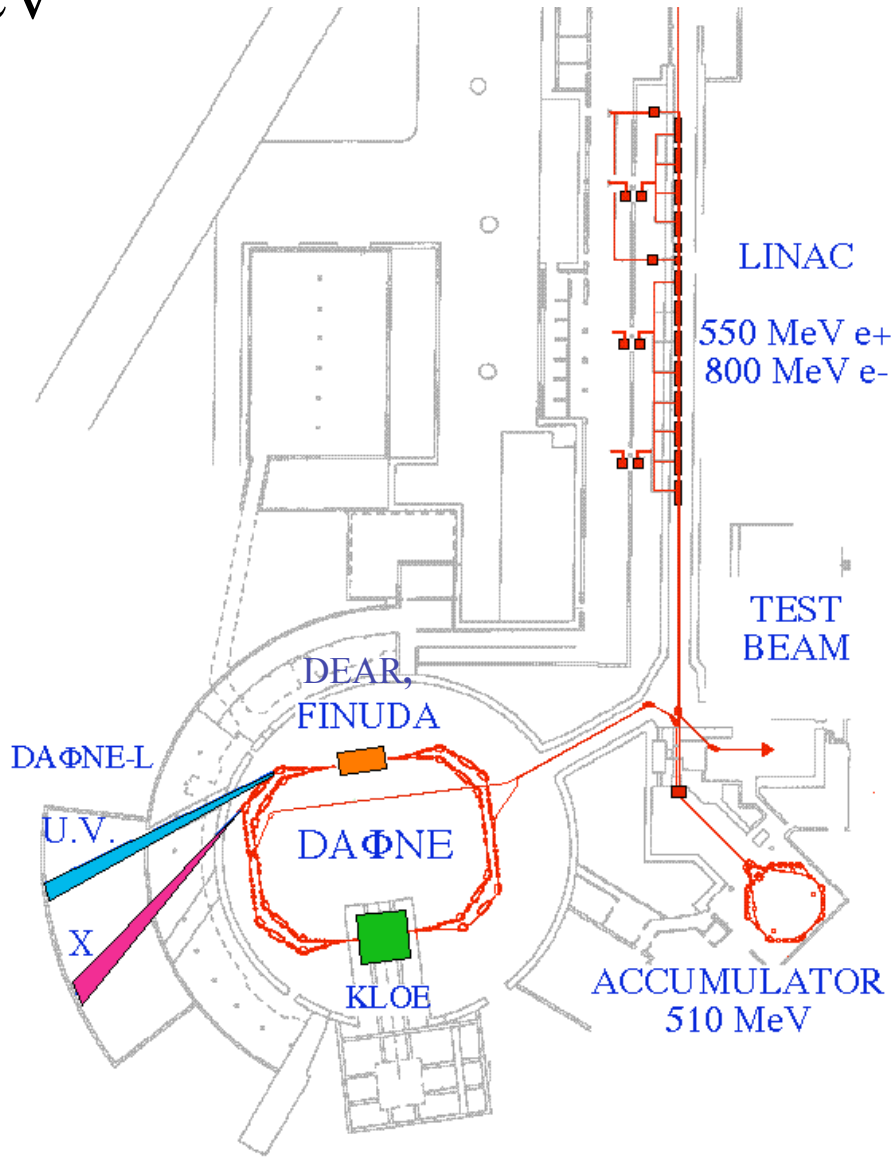
DAΦNE: A Φ-Factory

(**D**ouble **A**nnular Φ-Factory for **N**ice **E**xperiments)

e^+e^- - collider with $\sqrt{s} = m_\Phi \approx 1.0194$ GeV





2003: FINUDA run, DAΦNE upgrades

2004: KLOE data taking since April:

$L_{peak} = 9 \cdot 10^{31} cm^{-2} s^{-1}$

$L_{avg} = 6 \cdot 10^{31} cm^{-2} s^{-1}$

Goal: $L > 10^{32} cm^{-2} s^{-1}$ for 1-2 fb^{-1}/year

KLOE:

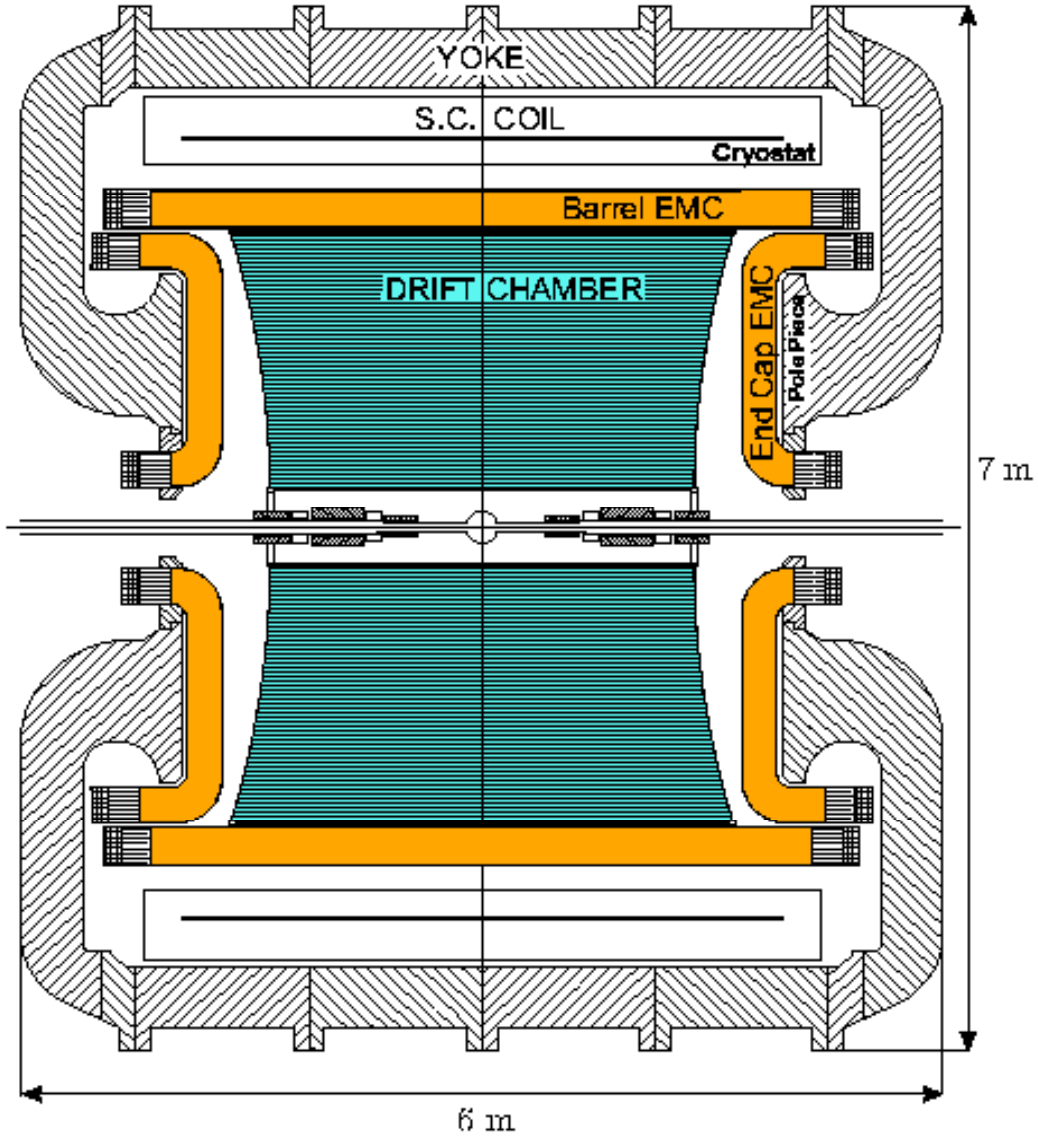
(KLOng Experiment)

- **Magnet:**
  Superconducting coil (B=0.52 T)

- **EM Calorimeter:**
  Lead/Scintillating fibres
  4880 PM

- **Driftchamber:**
  12582 Sense Wires
  52140 wires in total

- **Beryllium Beampipe:**
  R=10 cm, 0.5 mm thick

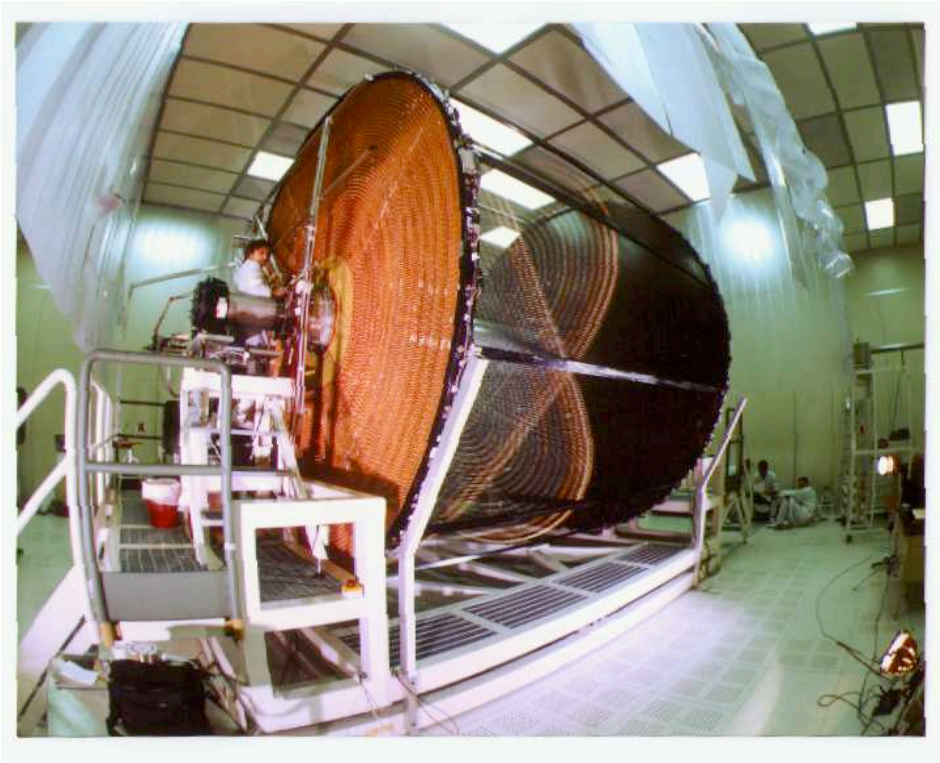


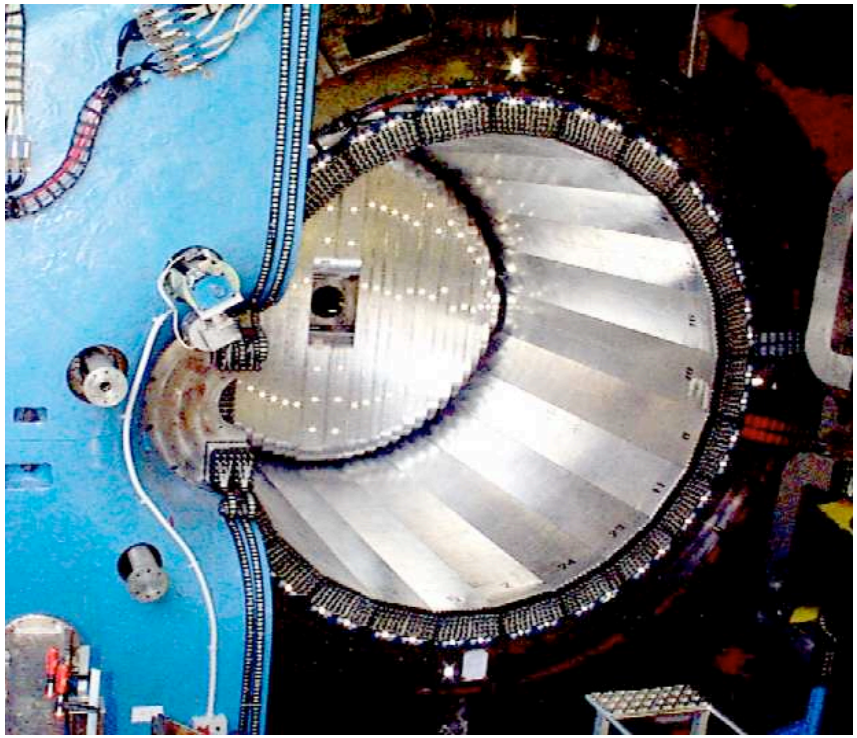
KLOE:

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

$\sigma_t = 54\ \mathrm{ps} / \sqrt{E(\mathrm{GeV})} \oplus 50\ \mathrm{ps}$

Driftchamber





Electromagnetic calorimeter

$\sigma_p/p = 0.4\%$ (for 90^0 tracks)

$\sigma_{xy} \sim 150\ \mu\mathrm{m}$, $\sigma_z \sim 2$ mm

KLOE: Physics...

• Hadronic cross section	*Paper submitted to Phys. Lett.* **B** □ A. Denig
• □□ $f_0(980)$ □	*Phys. Lett.* **B537**(2002)21 - new updates
• □□ $a_0(980)$ □	*Phys. Lett.* **B536**(2002)209 - new updates
• □□ □' □, □□	*Phys. Lett.* **B541**(2002)45 - new updates
• □□ □□, □$^+$□□^{0}	*Phys. Lett.* **B561**(2003)55
• Upper limit BR(□ □ □□□)	*Phys. Lett.* **B591**(2004)45
• Dalitz plot □□ □$^+$□□^{0}, □^{0}□^{0}□^{0}	Preliminary results
• □ leptonic width	Preliminary results
• □ □ □$^+$ □□	Preliminary result
• other rare □ – Decays	work in progress
• …	

• K_S □ □$^+$□□(□)/ K_S □ □^{0}□^{0}	*Phys. Lett.* **B538** 21 (2002)
• K_S mass	*KLOE Note 181* (http://www.lnf.infn.it/kloe)
• K_S □ □e□	*Phys. Lett.* **B537** 21 (2002)
• K_S □ □^{0}□^{0}□^{0}	preliminary results
• $K^\pm$□ □$^\pm$□^{0}□^{0}	hep-ex/0307054, submitted to *Phys. Lett.* **B**
• K_L □ □□	*Phys. Lett.* **B566** 61 (2003)
• K_L lifetime	preliminary results
• K_L absolute BR's	preliminary results
• K_SK_L interference	in progress
• $K^\pm$□ □$^\pm$□^{0}/ $K^\pm$□ □$^\pm$□	in progress
• $K^\pm$ Lifetime	in progress
• $K^\pm$ absolute BRs	in progress
• …	

□□ $f_0(980)$□□ □$^+$□$^-$□:

Neutral channel: Br(□□ □^{0}□^{0}□)=(1.09±0.03$_{stat}$ ±0.05$_{syst}$)·10^{-4} *Phys. Lett. B537 (2002), 21*

Charged channel: Search for $f_0(980)$ → □$^+$□$^-$ in □$^+$□$^-$□ events to extract properties of the scalar meson f_0

Background from:
- *e^+e^-□ □$^+$□$^-$□ via ISR (rad. return to □,□)*
- *e^+e^-□ □$^+$□$^-$□ via FSR*
- *□□ (□□ □□)□*

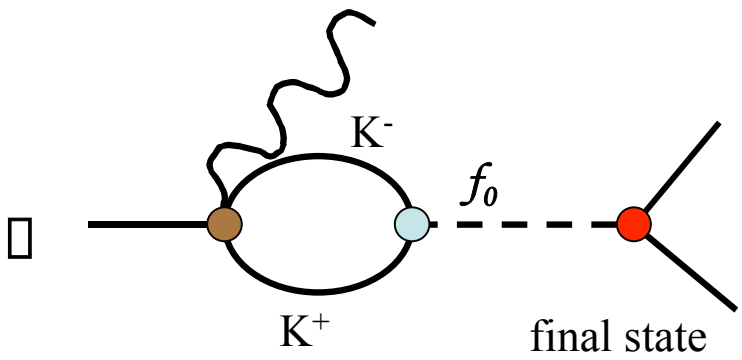
FSR and f_0 interference expected

Analysis selection: 45 < □$_□$ < 135° ➔ ISR reduced

$$\frac{d\square}{dM} \quad \left|A(ISR) + A(FSR) + A(f_0) + A(\square\square)\right|^2$$

$A(f_0)$:

Decay through charged kaon-Loop



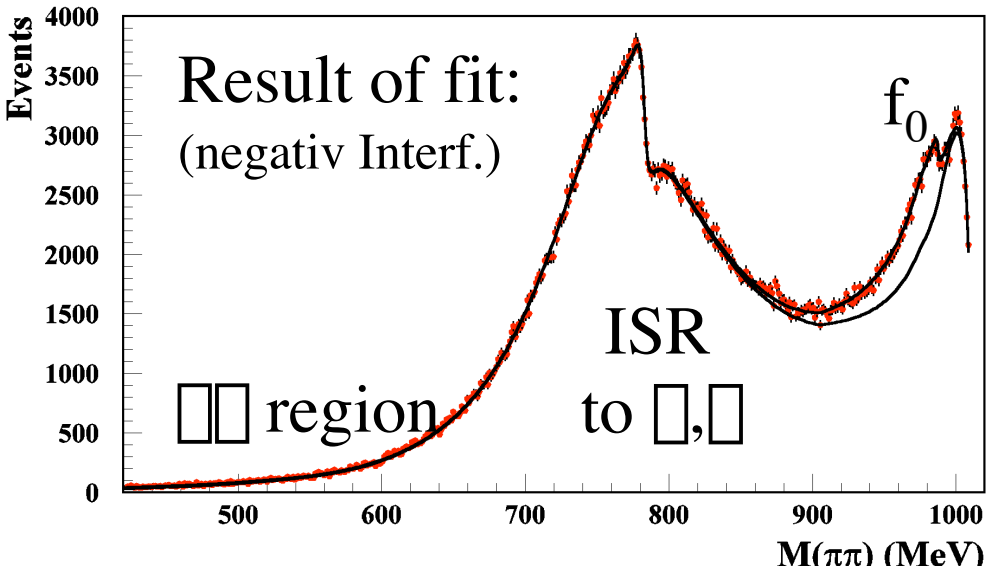
- g(□KK) from □(□ □ K^+K^-)
- g(f_0KK)
- g(f_0□□)

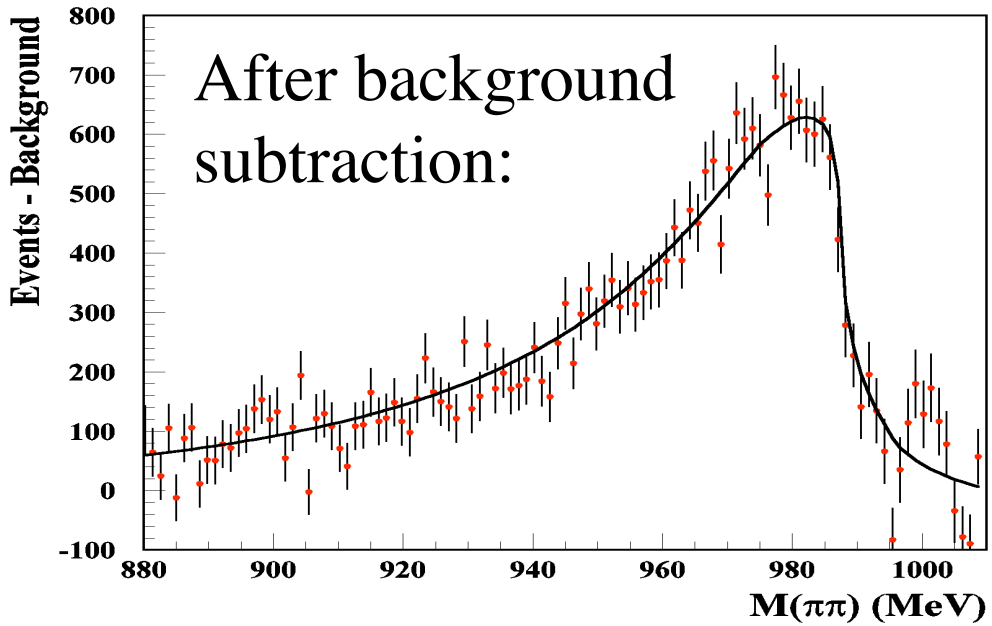
□□ final state interaction included

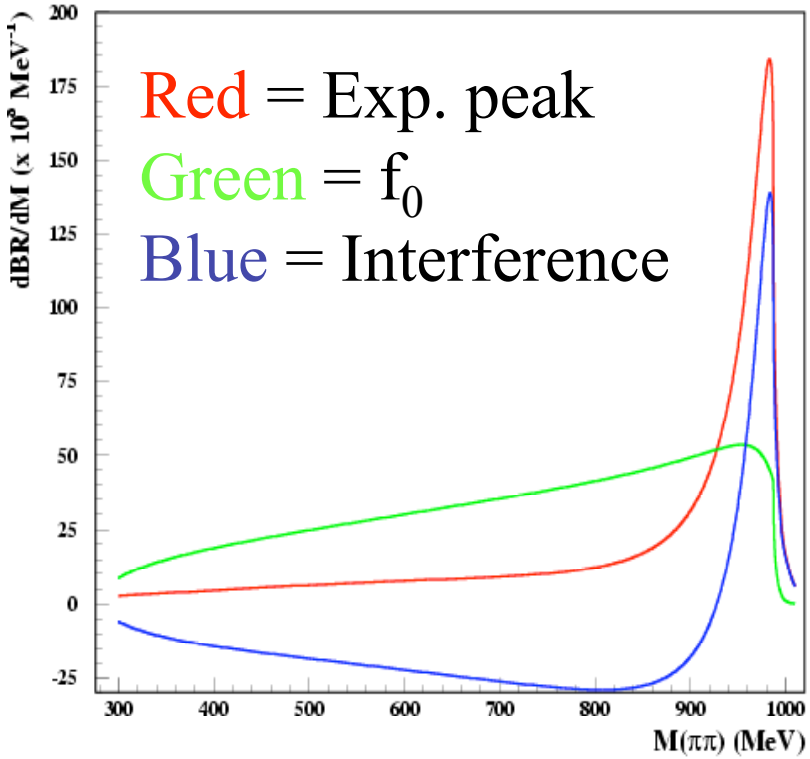
(Phys. Rev. D57, 1987 (1998))

□□ f_0(980)□□ □+□-□:

Fit $M_{□□}$ spectrum with signal +background parameterizations:







Strong cancellation between f_0 peak and the interference terms

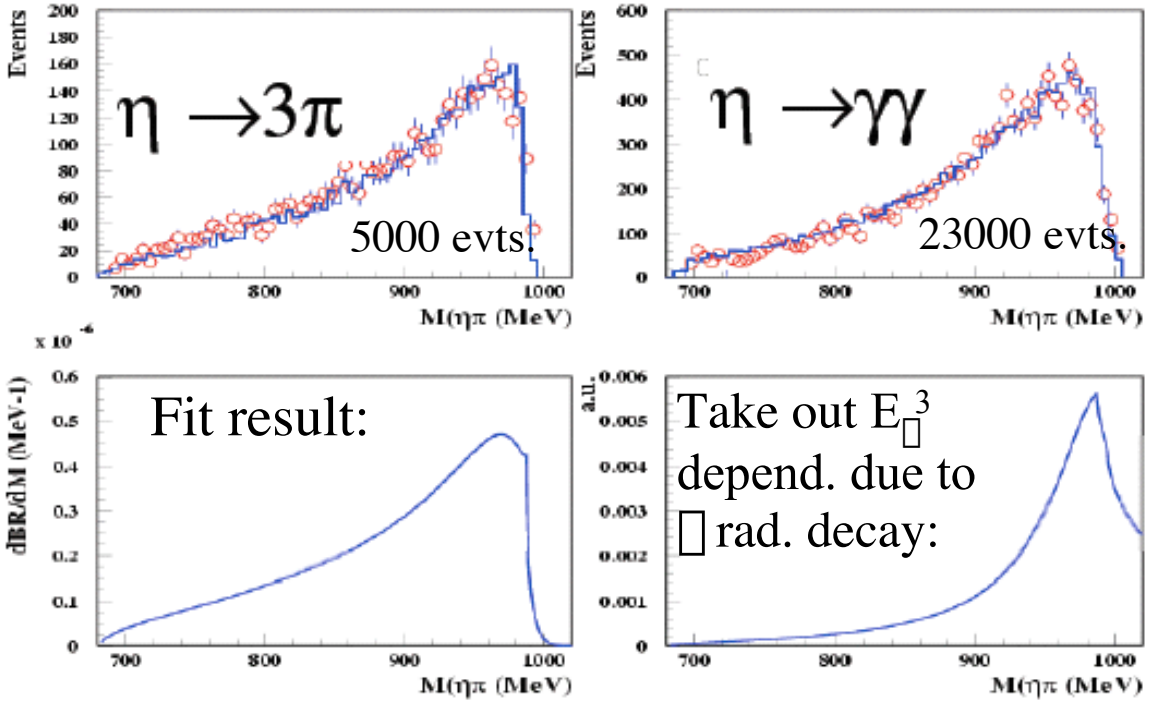
$\phi \to a_0(980)\gamma \to \eta\pi^0\gamma$

2 decay chains: $\phi \to a_0\gamma \to \eta\pi^0\gamma$

- $\phi \to \pi^+\pi^-\pi^0$ — 5 clust., 2 charged tracks
- $\phi \to \pi\pi$ — 5 clust., no charged tracks

2002 KLOE result (Phys. Lett. B536, 209): Br($\phi \to a_0\gamma$)=(7.4±0.7)·10^{-5}

Fit $\eta\pi^0$ inv. mass distribution with charged kaon-loop model:



KLOE04: (prel.)

$\phi \to \pi^+\pi^-\pi^0$:	Br($\phi \to \eta\pi^0\gamma$) = (7.45±0.19)·10^{-5}
$\phi \to \pi\pi$:	Br($\phi \to \eta\pi^0\gamma$) = (7.25±0.15)·10^{-5}

□□ □□□

□□ □□ → □□□
→ E_{rad}=363 MeV } 4□final state

C violating decay:
Br < $5\cdot10^{-4}$@95% CL (PDG02)

Reject background by cutting on 2□inv. mass to eliminate channels containing □^{0}.

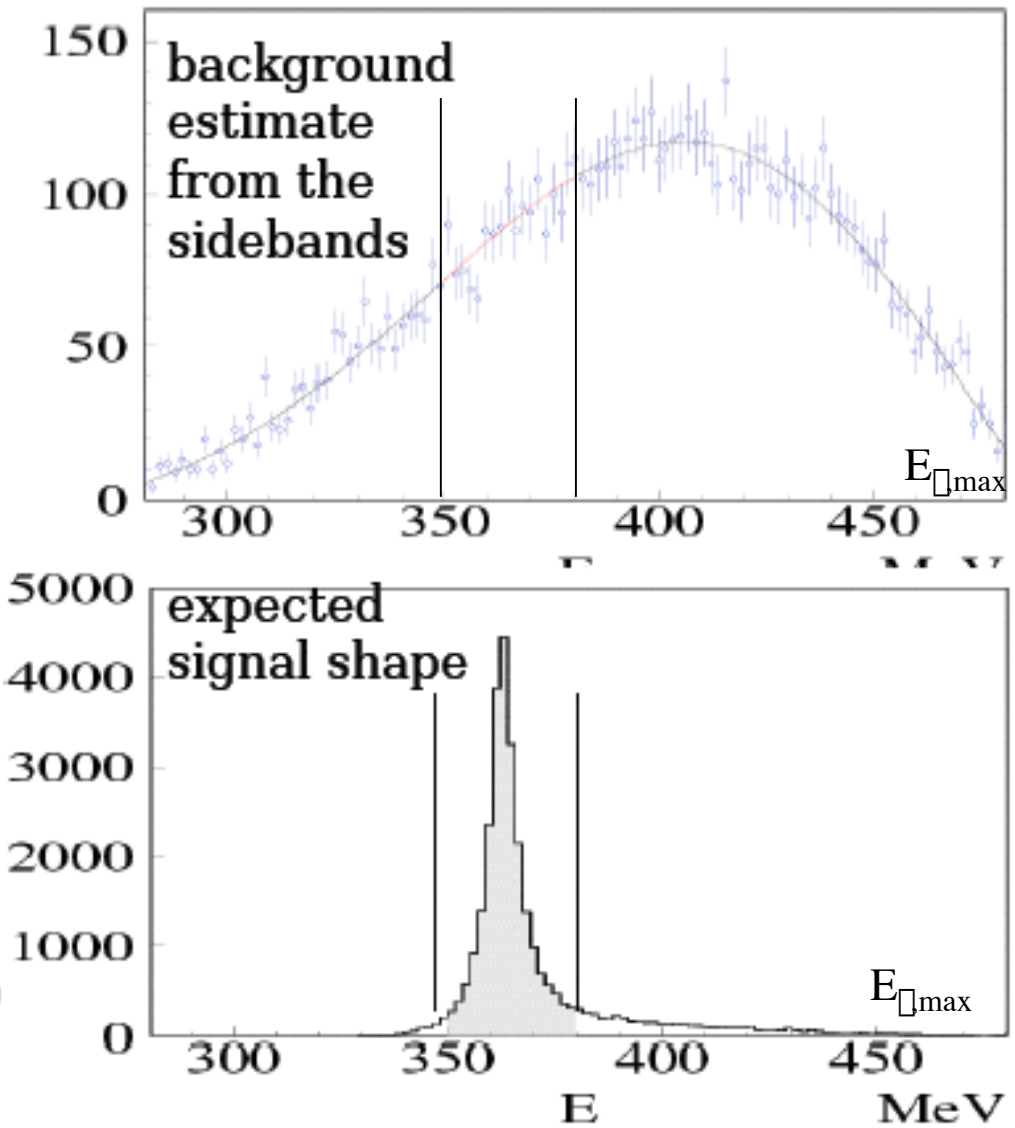
Fit signal peak in $E_{□max}$,
Background estimate from polynom. fit of sidebands:

$N_{□□\ □□□}$<80.8@95%CL

Normalizing to □□ □^{0}□^{0} □^{0}:

$\boxed{Br(□□\ □□□) < 2.0\cdot10^{-5}@95\%\ CL}$

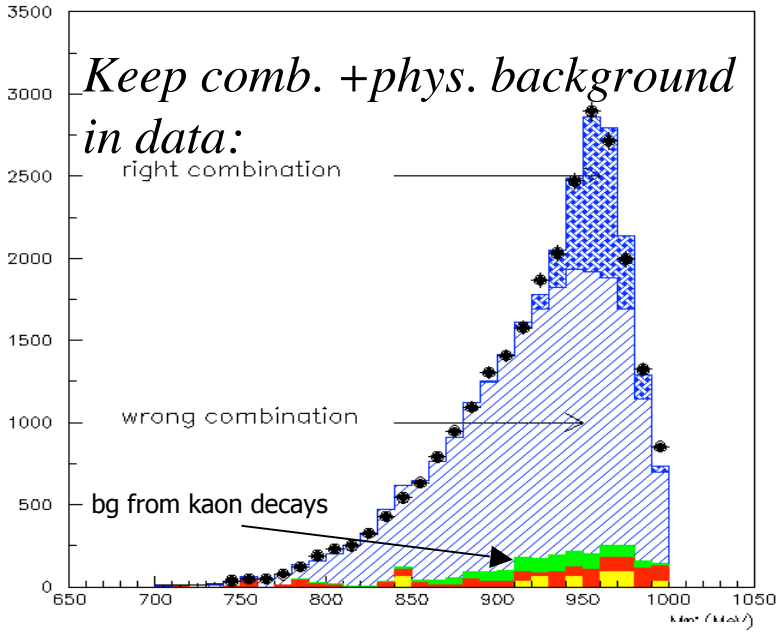
Phys. Lett. B591, 49 (2004)



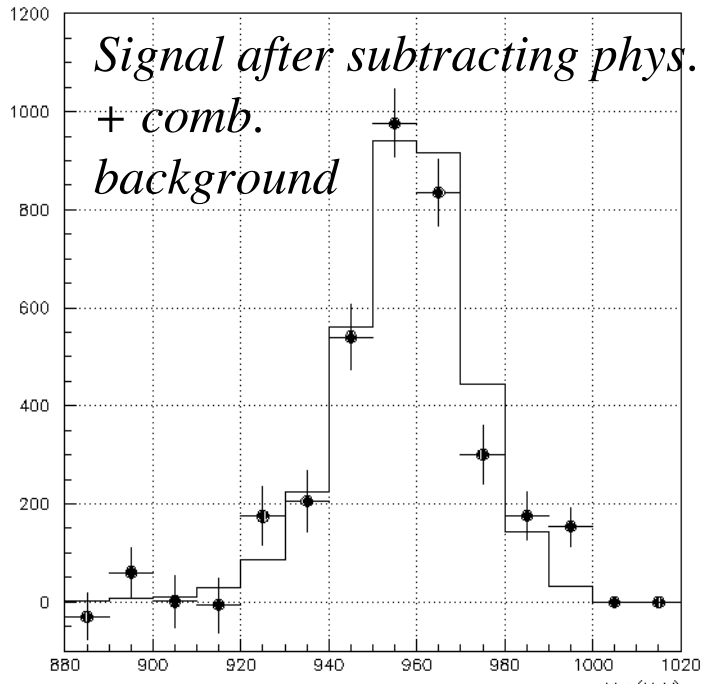
Br(□□ □□□)/Br(□□ □□)

$R = Br(\square\square\ \square\square\square)/Br(\square\square\ \square\square) = (4.7 \pm 0.5_{stat} \pm 0.3_{syst}) \cdot 10^{-3}$ *[Phys. Lett. B541, 45(2002)]*

KLOE04: chrg: □□ □□□, □□□ □+□-□, □□ □0□0□0 neut: □□ □□□, □□□ □0□0□, □□ □+□-□0 } □+□-7□ final state



M□□6□



M□□6□

Normalize to □□ □0□0 □0:

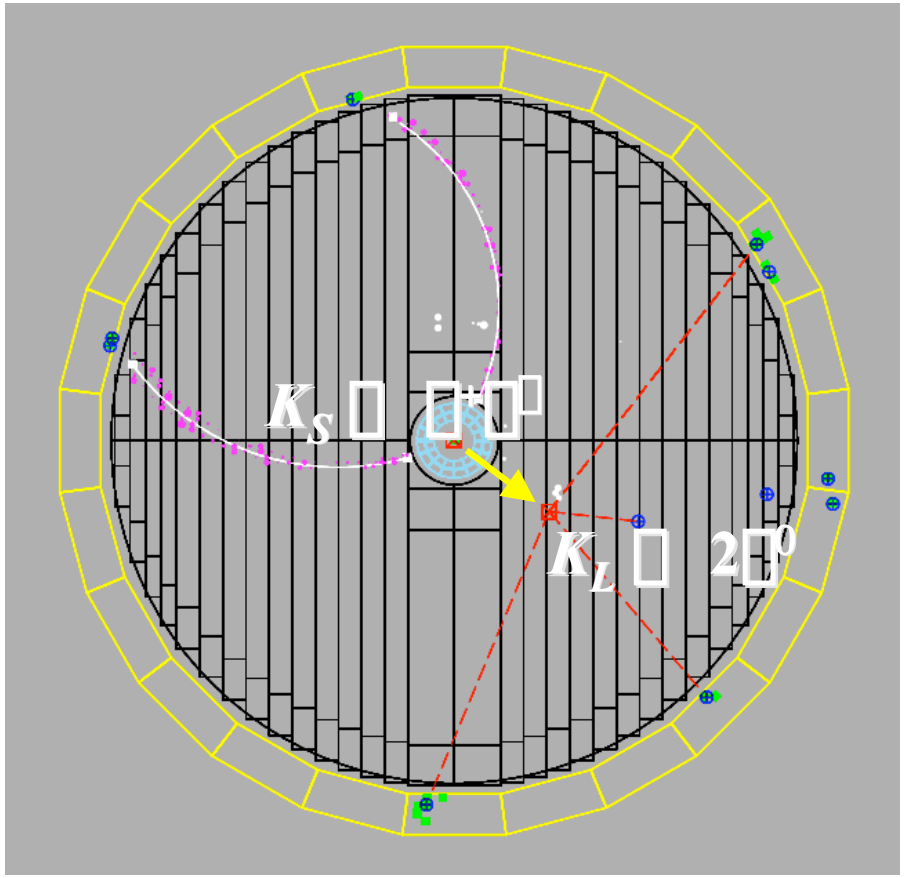
Corr. factor due to □/□□ □(□□)□Interf.

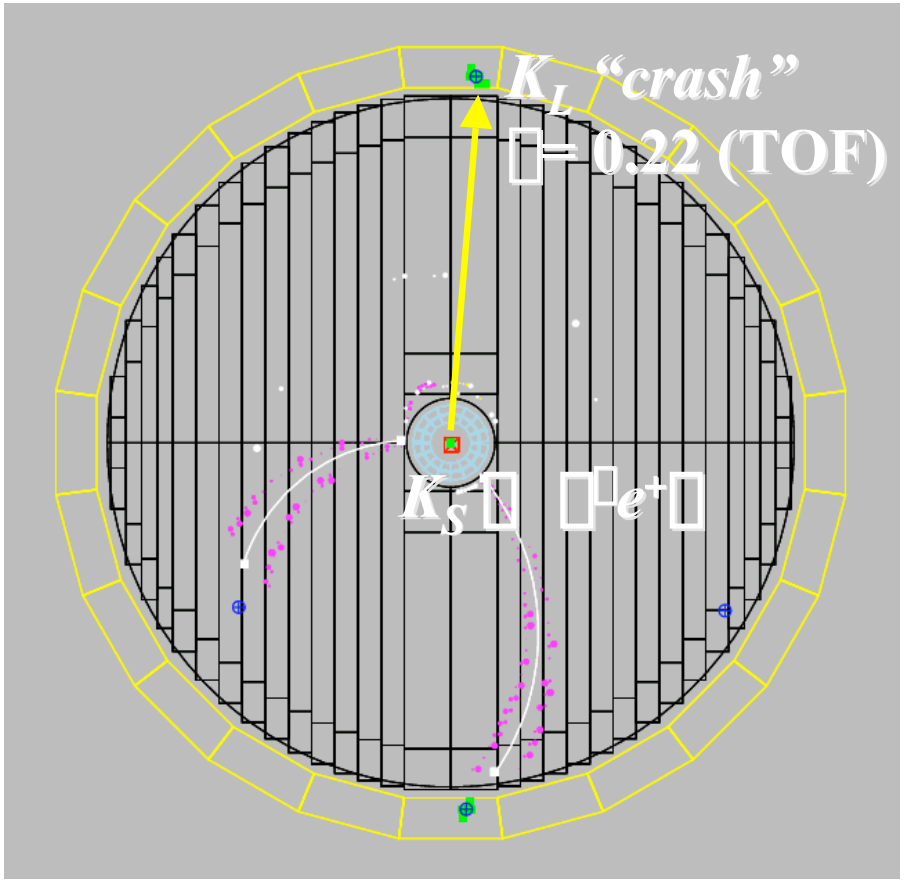
$$R = \frac{N_{\square\square}}{N_{\square\square}} \frac{\square_{\square\square} Br(\square\square\ 3\square^0)}{\left[Br_{chrg}\square_{chrg} + Br_{neut}\square_{neut}\right]} K_{\square} = (4.9 \pm 0.1_{stat} \pm 0.2_{syst}) \cdot 10^{\square 3}$$

KLOE prel.

Neutral kaon physics:

Kaon pair production at ϕ-factory allows for tagged K_L-K_S-"beams":





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

Efficiency ~ 70% $\times$ BR($K_S \to \pi^+\pi^-$)

K_L angular resolution: ~ 1°

K_L momentum resolution: ~ 2 MeV

K_S tagged by K_L interaction in EmC

Efficiency ~ 30%

K_S angular resolution: ~ 1°

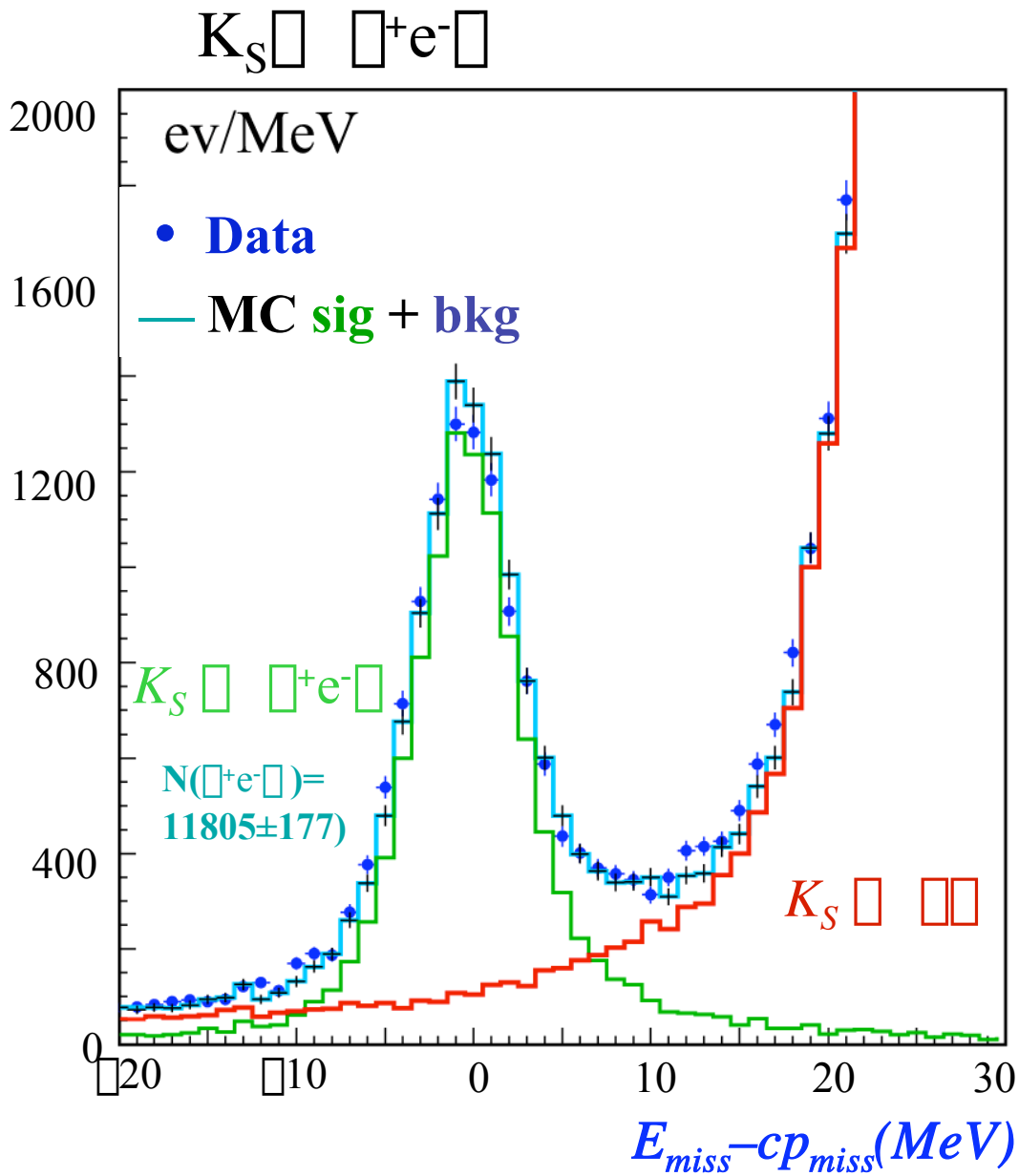
K_S momentum resolution: ~ 2 MeV

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

Selection:

- $K_S \to \pi e \nu$ selected by K_L-"Crash" tag
- Signal- and normalizing sample $K_S \to \pi^+\pi^-$ are further kinematically separated $E_{miss} - c \cdot p_{miss}$
- Obtain number of signal events via fit of data points to the linear comb. of MC-spectra for signal + Background

Radiative Correction simulated within MC (w/o E_γ-cutoff!)



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

Normalize number of signal counts to number of $K_S \to \pi^+\pi^-(\gamma)$ in the same data set [$Br(K_S \to \pi^+\pi^-(\gamma)$ taken from PDG03] :

KLOE04 preliminary results:

$$BR(K_S \to \pi^- e^+ \nu) = (3.54 \pm 0.05_{stat} \pm 0.05_{syst})\ 10^{-4}$$
$$BR(K_S \to \pi^+ e^- \bar{\nu}) = (3.54 \pm 0.05_{stat} \pm 0.04_{syst})\ 10^{-4}$$

$$\boxed{\mathbf{BR(K_S \to \pi e \nu) = (7.09 \pm 0.07_{stat} \pm 0.08_{syst})\ 10^{-4}}}$$

Publ. Result: $(6.91 \pm 0.34_{stat} \pm 0.15_{syst})\ 10^{-4}$ [KLOE '02]

Semilept. charge asymmetry for the K_S (probe CP-viol. in mixing):

$$A_S = \frac{\Gamma(K_S \to \pi^- e^+ \nu) - \Gamma(K_S \to \pi^+ e^- \bar{\nu})}{\Gamma(K_S \to \pi^- e^+ \nu) + \Gamma(K_S \to \pi^+ e^- \bar{\nu})} = 2\ \mathrm{Re}(\varepsilon) \sim 3 \cdot 10^{-3}$$

$$\boxed{\mathbf{A_S = (-2 \pm 9_{stat} \pm 6_{syst}) \cdot 10^{-3}}}$$ Kloe prel.

Future: $2 fb^{-1} \Rightarrow \Delta(A_S) = 3 \cdot 10^{-3}$

$20 fb^{-1} \Rightarrow$ Test of CPT parameter $\mathrm{Re}(\varepsilon)$ via $A_S - A_L$

Analysis of K_L decays:

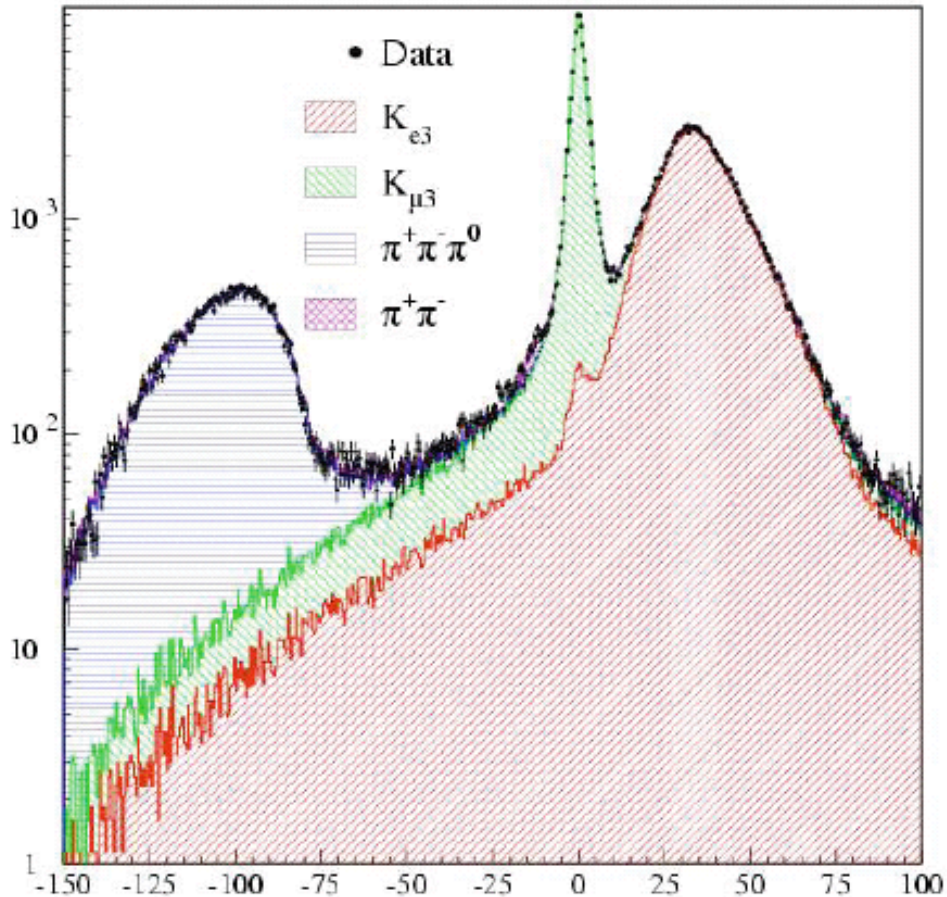
$13 \cdot 10^6$ K_L tagged by $K_S \to \pi^+\pi^-$ decay

Search for K_L decay vertex in fid. volume along K_L line of flight

- *from photons for $K_L \to 3\pi^0$*
- *from charged tracks for $K_L \to \pi e \nu, \pi\pi\pi, \pi^+\pi^-\pi^0$*

Separate charged channels kinematically via $|\mathbf{p}_{miss}|$-E_{miss} and obtain number of signal events by fitting with linear comb. of MC samples.

Result of fit (charged channels):



smaller value of $|\mathbf{p}_{miss}|$-E_{miss} (MeV) in $\pi\pi$ or $\pi\pi$ hyp

Preliminary results:

$BR(K_L \to \pi e \nu) = (0.3994 \pm 0.0006_{stat} \pm 0.0034_{syst})$

$BR(K_L \to \pi\pi\pi) = (0.2708 \pm 0.0005_{stat} \pm 0.0025_{syst})$

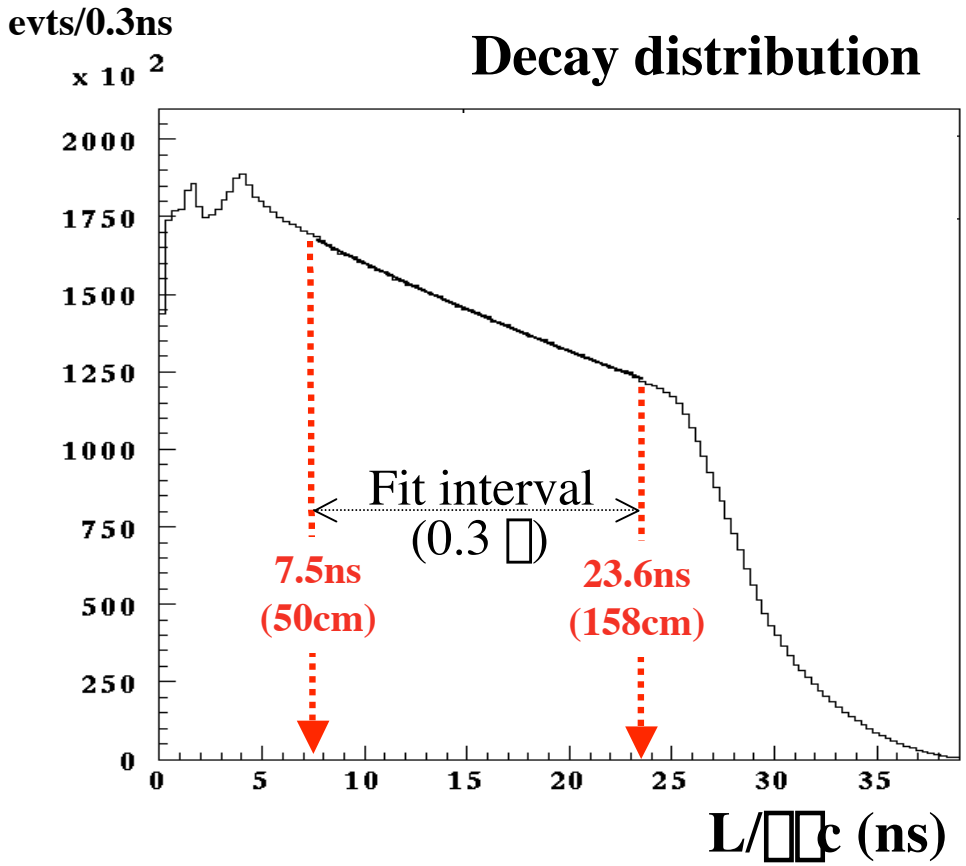
$BR(K_L \to \pi^+\pi^-\pi^0) = (0.1271 \pm 0.0004_{stat} \pm 0.0010_{syst})$

$BR(K_L \to 3\pi^0) = (0.2014 \pm 0.0003_{stat} \pm 0.0022_{syst})$

obtained using $\tau(K_L) = 51.15 \pm 0.20_{stat} \pm 0.40_{syst}$

K_L lifetime:

The K_L momentum is well known, and ca. 30% of the kaons decay inside the detector. Using $K_L \to \pi^0\pi^0\pi^0$ events - tagged with $K_S \to \pi^+\pi^-$ - the neutral vertex is reconstructed using time of flight technique (σ_τ=1.5 cm).



KLOE Result (preliminary)

$$\tau(K_L) = (51.15 \pm 0.20_{stat} \pm 0.40_{syst})\ \text{ns}$$

τ(PDG) (ave) = (51.5 ± 0.40) ns

Checks with data for:

- neutral vertex reconstruction eff.
- photon detection efficiency
- time-scale calibration

with $K_L \to \pi^+\pi^-\pi^0$ events

Systematic error preliminary!

K_L lifetime from $\Sigma Br(K_L \to X) = 1.$: $\tau(K_L) = (51.35 \pm 0.05_{stat} \pm 0.26_{syst})$ ns

V_{us} from semileptonic decays:

Master formula:

$$\Gamma(K_{\ell 3}) \propto |V_{us} \cdot f_+^{K\pi}(0)|^2 \, I(\lambda_+) \, (1 + \delta I(\lambda_+)/2 + \delta_{EW})^2 \cdot S_{ew}$$

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

$I(\lambda_t)$ is the integral of the phase space density after factorizing out $f_+^{K\pi}(0)$ and radiative corrections. λ_+ describes the dependence of the vector and scalar form factor on momentum transferred t (slopes λ_+, λ_{+}'').

KLOE preliminary results:

$$|V_{us}| \cdot f_+^{K\pi}(0)[K_{Se3}] = 0.2171 \pm 0.0017$$
$$|V_{us}| \cdot f_+^{K\pi}(0)[K_{Le3}] = 0.2147 \pm 0.0014$$
$$|V_{us}| \cdot f_+^{K\pi}(0)[K_{L\mu 3}] = 0.2167 \pm 0.0015$$

Using $f_+^{K\pi}(0)$ from Leutwyler, Roos (1984): $f_+^{K\pi}(0)=0.961 \pm 0.008$ one gets from unitarity:

$$(1-|V_{ud}|^2)^{1/2} \cdot f_+^{K\pi}(0) = 0.2177 \pm 0.0028$$

V_{ub} negligible

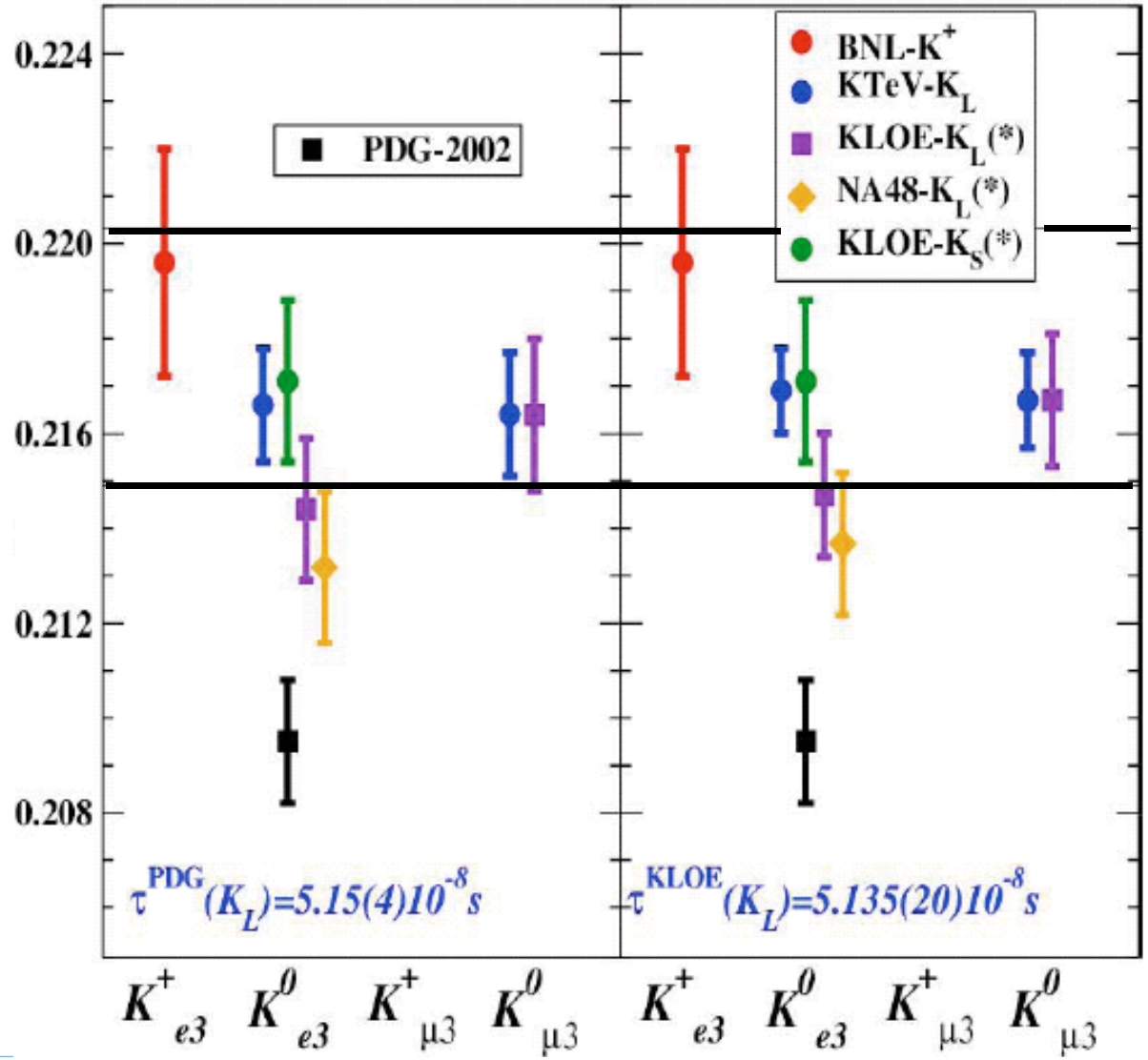
V_{us} from semileptonic decays:

Compare measurements of $|V_{us}|\cdot f_+^{K\square}(0)$

$\square(K_S\square\ \square e\square)$ from KLOE
$\square(K_L\square\ \square l\square)$ from KLOE
with
$\square(K^+\square\ \square^0 e^+\square)$ from E865
$\square(K_L\square\ \square l\square)$ from KTEV
$\square(K_L\square\ \square e\square)$ from NA48
$\square(K_L\square\ \square e\square)$ from PDG02

But unitarity band depends on $f_+^{K\square}(0)$…

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



Summary:

KLOE has collected 500pb^{-1} of data in 2000-2002:

- Analysis of this data in progress, (prel.) results on:
  - f_0, a_0 decays
  - η, η' decays
  - hadr. cross section (talk by A. Denig, Friday 14.00h)
  - K_L, K_S decays and lifetimes
- Ongoing analysis in
  - K_+, K_- decays and lifetimes
  - $K_S K_L$ interference
  - …

KLOE has resumed data taking and expects to collect 2 fb^{-1} in 2004/05:

- improved analysis on rare decays and quantum interference