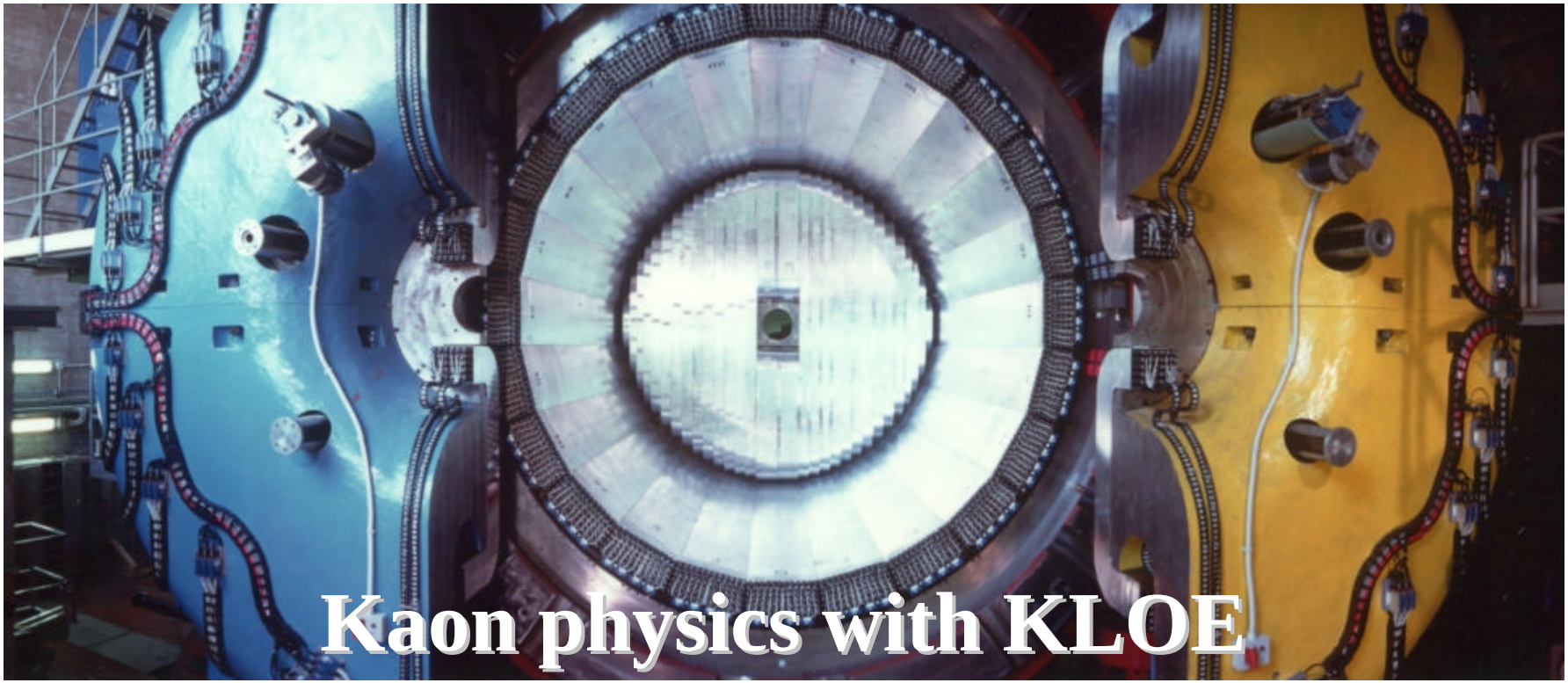


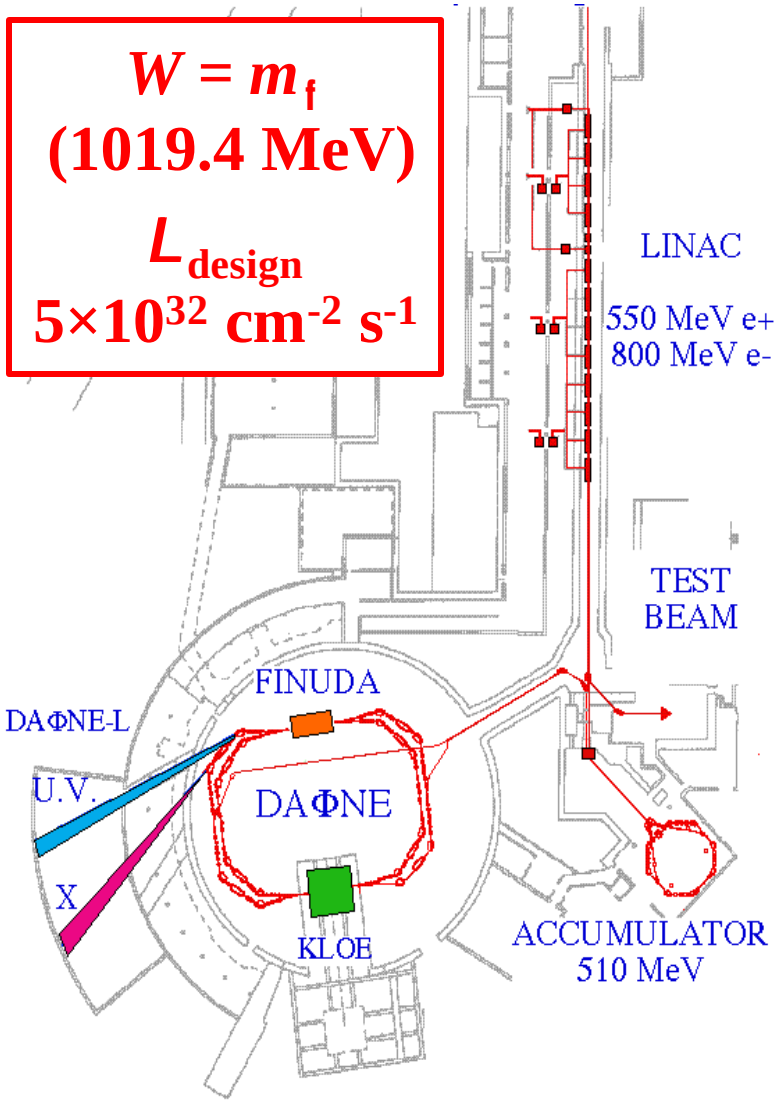
Kaon physics with KLOE

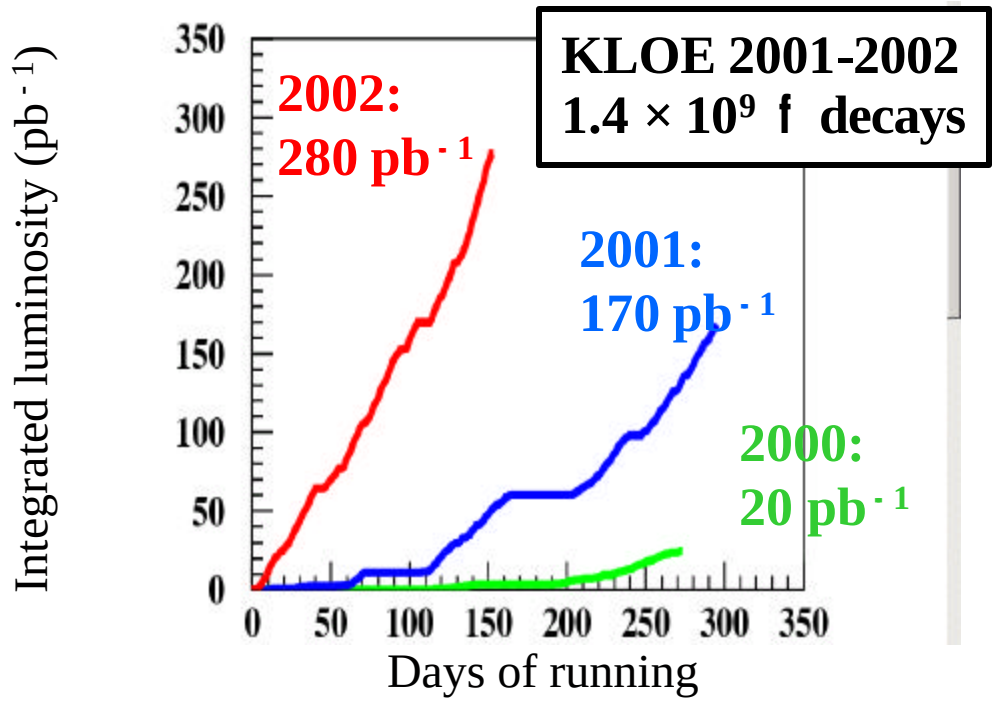
M. Moulson
INFN/KLOE-Frascati

Workshop on Future Kaon Experiments at the AGS
Brookhaven, 13 May 2004

DAΦNE: the Frascati φ factory

$W = m_\phi$
(1019.4 MeV)
L_{design}
5×10^{32} cm^{-2} s^{-1}





2002 best L_{peak} 7.8×10^{31} cm^{-2} s^{-1}

2002 avg L $\sim 4 \times 10^{31}$ cm^{-2} s^{-1}

Machine upgrades for 2004:

$L_{avg} > 10^{32}$ cm^{-2} s^{-1} ® 2 fb^{-1}/yr

Kaon physics at DAFNE

s(e⁺e⁻ ® f) » 3mb

$K_S K_L$ (K^+K^-) produced in pure $J^{PC} = 1^{--}$ state

Principal f decays	
K^+K^-	**49.1%**
$K_S K_L$	**34.3%**
rp	**15.4%**
hg	**1.3%**

$$K_S, K^+ \longleftarrow f \longrightarrow K_L, K^-$$

$$\frac{1}{\sqrt{2}}\left(|K_L,\mathbf{p}\rangle|K_S,-\mathbf{p}\rangle - |K_L,-\mathbf{p}\rangle|K_S,\mathbf{p}\rangle\right)$$

Observation of $K_{S,L}$ signals presence of $K_{L,S}$

Allows precision measurement of absolute BRs

Allows interference measurements of $K_S K_L$ system

$p_{L,S}$ = 110 MeV
$\beta_{L,S}$ = 0.22

l_S = 6 mm: K_S decays near interaction point

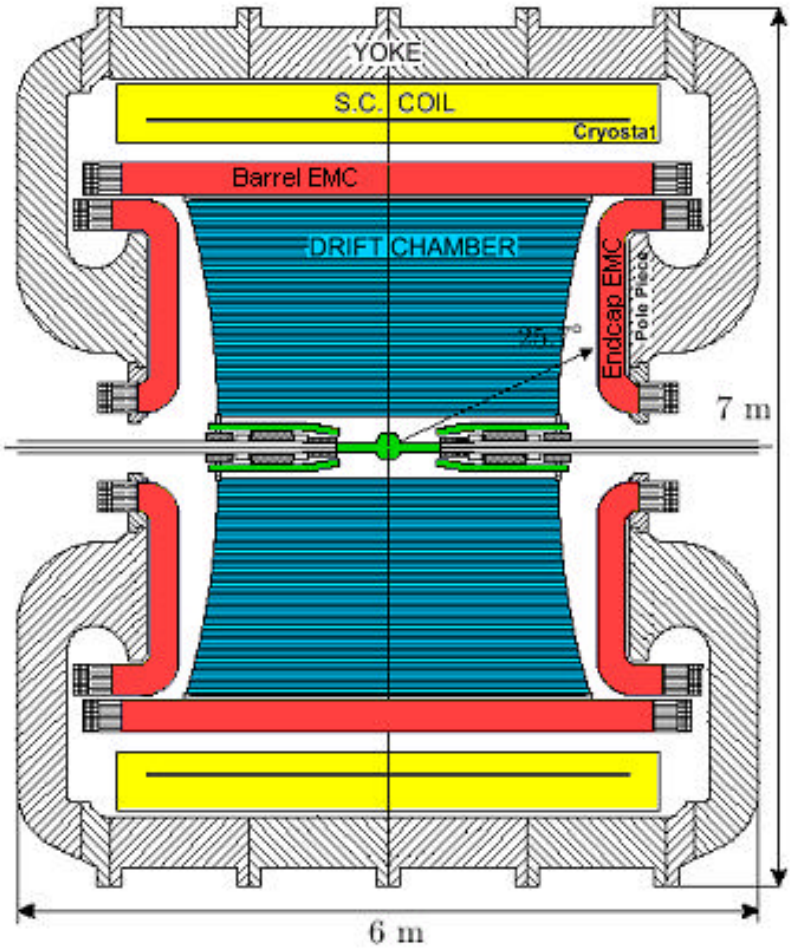
l_L = 3.4 m: Appreciable acceptance for K_L (~0.5 l_L)

Physics vs. luminosity: perspectives

0.5 fb^{-1} 5×10^{8} K_SK_L	**KLOE today**	Limit on BR($K_S \to 3\pi^0$) at 10^{-7} level $K_S \to \pi e \nu$ charge asymmetry (A_S) to 10^{-2} V_{us} from $K_{\ell 3}$ decays at few $\times$ 10^{-3} level
2 fb^{-1} 2×10^{9} K_SK_L	**KLOE '04-'05**	Limit on $K_S \to 3\pi^0$ at 10^{-8} level A_S to 4×10^{-3} First studies of K_SK_L system with interference
40 fb^{-1} 4×10^{10} K_SK_L	**Original KLOE program**	Re ε'/ε at 10^{-4} level Im ε'/ε at 10^{-3} level from K_SK_L interference
200 fb^{-1} 2×10^{11} K_SK_L	**DAΦNE2**	High-precision studies of K_SK_L system via interference measurements Competitive measurement of Re δ from A_S BR($K_S \to 3\pi^0$) and BR($K_S \to \pi^0\ell\ell$) to 20%

$K^+ \to \pi^+\nu\nu$, $K_L \to \pi^0\nu\nu$, and $K_L \to \pi^0\ell^+\ell^-$ probably not within reach

The KLOE experiment



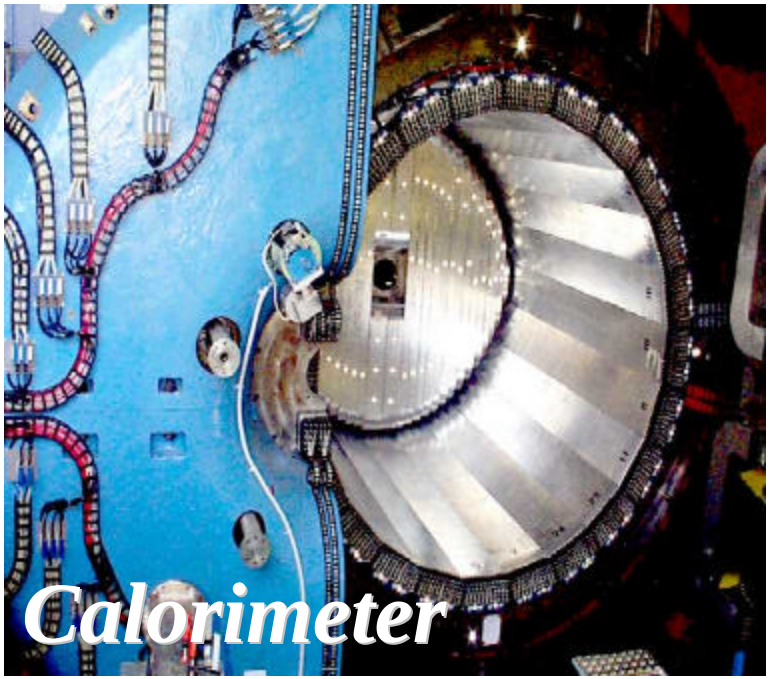
Be beam pipe (0.5 mm thick)
Instrumented permanent magnet quadrupoles (32 PMT's)

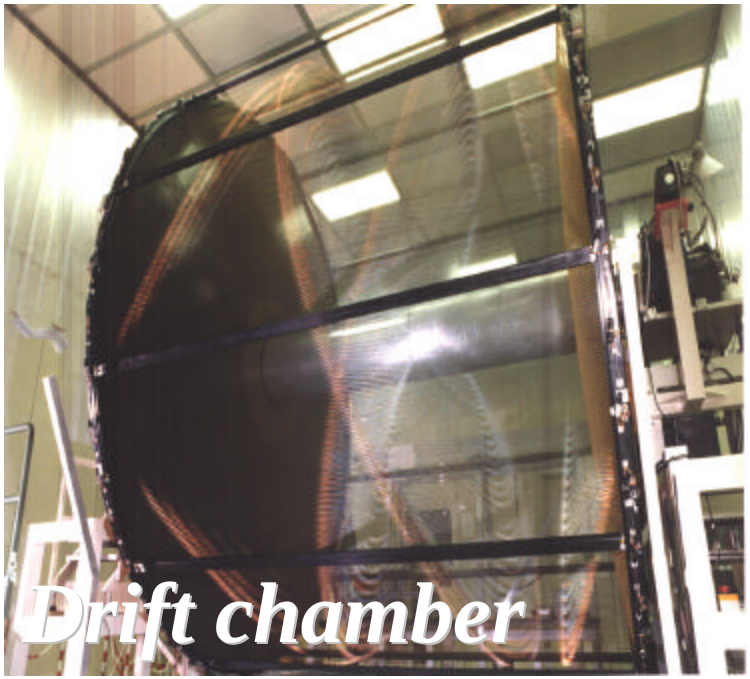
Drift chamber (4 m Æ ´ 3.3 m)
90% He + 10% IsoB, CF frame
12582 stereo sense wires

Electromagnetic calorimeter
Lead/scintillating fibers
4880 PMT's

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

KLOE detector specifications





σ_E/E 5.7% /ÖE(GeV)

σ_t 54 ps /ÖE(GeV) Å 50 ps
(relative time between clusters)

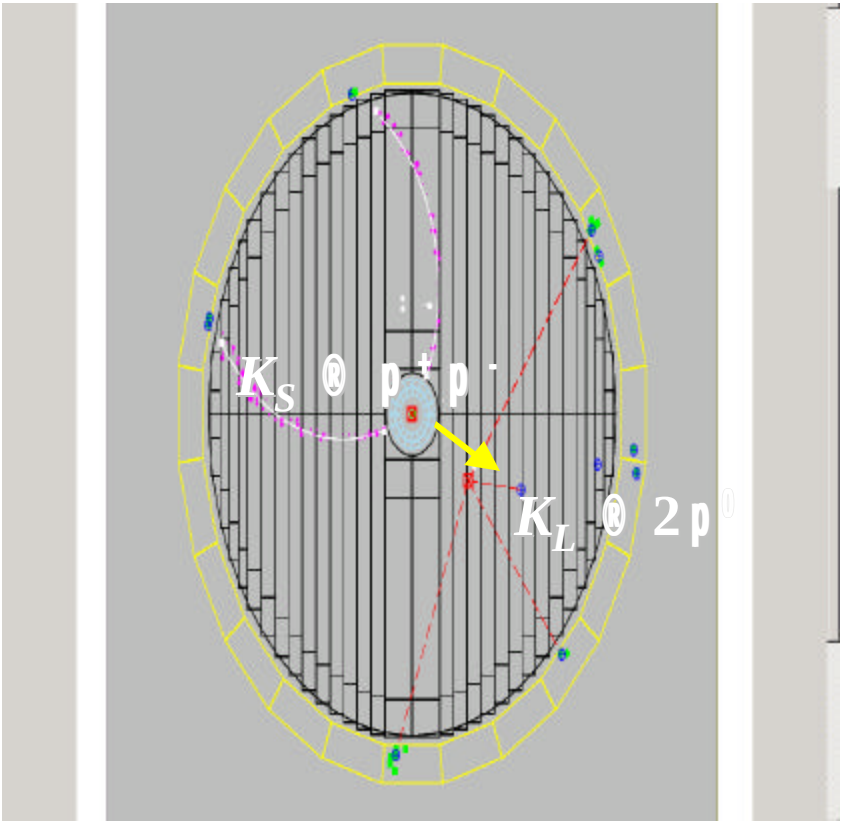
$\sigma_L(\gamma\gamma)$ ~2 cm (π^0 from K_L ® $\pi^+\pi^-\pi^0$)

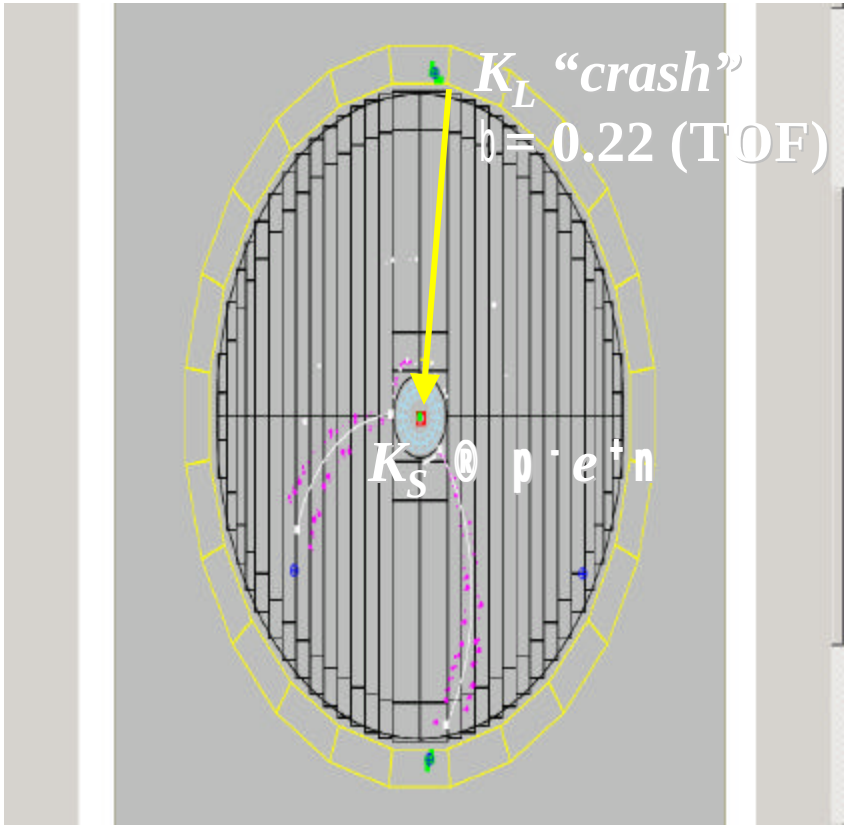
σ_p/p 0.4 % (tracks with θ > 45°)

σ_x^{hit} 150 mm (xy), 2 mm (z)

σ_x^{vertex} ~1 mm

Tagged K_L and K_S "beams"





K_L tagged by K_S ® p+p- vertex at IP
Efficiency ~ 70% (mainly geometrical)
K_L angular resolution: ~ 1°
K_L momentum resolution: ~ 1 MeV

K_S tagged by K_L interaction in EmC
Efficiency ~ 30% (largely geometrical)
K_S angular resolution: ~ 1° (0.3° in f)
K_S momentum resolution: ~ 1 MeV

$K_S \to \pi^0\pi^0\pi^0$ – *tests of CP and CPT*

Observation of $K_S \to 3\pi^0$ signals *CP* violation in mixing and/or decay:

If *CPT* conserved: $\Gamma_S = \Gamma_L |\epsilon + \epsilon'_{000}|^2$ **BR($K_S \to 3\pi^0$) ~ 2×10^{-9}**

Best results: BR < 1.4×10^{-5} 90% CL SND '99

BR < 1.4×10^{-6} 90% CL NA48 '03 preliminary

Uncertainty on $K_S \to 3\pi^0$ amplitude currently limits precision on Im δ

From unitarity: $(\epsilon_{S,L} = \epsilon \pm \delta)$

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

Best results: Im $\delta = (2.4 \pm 5.0) \times 10^{-5}$ CPLEAR '99

Im $\delta = (-1.2 \pm 3.0) \times 10^{-5}$ NA48 '03 preliminary

A limit on BR($K_S \to 3\pi^0$) at 10^{-7} level would limit:

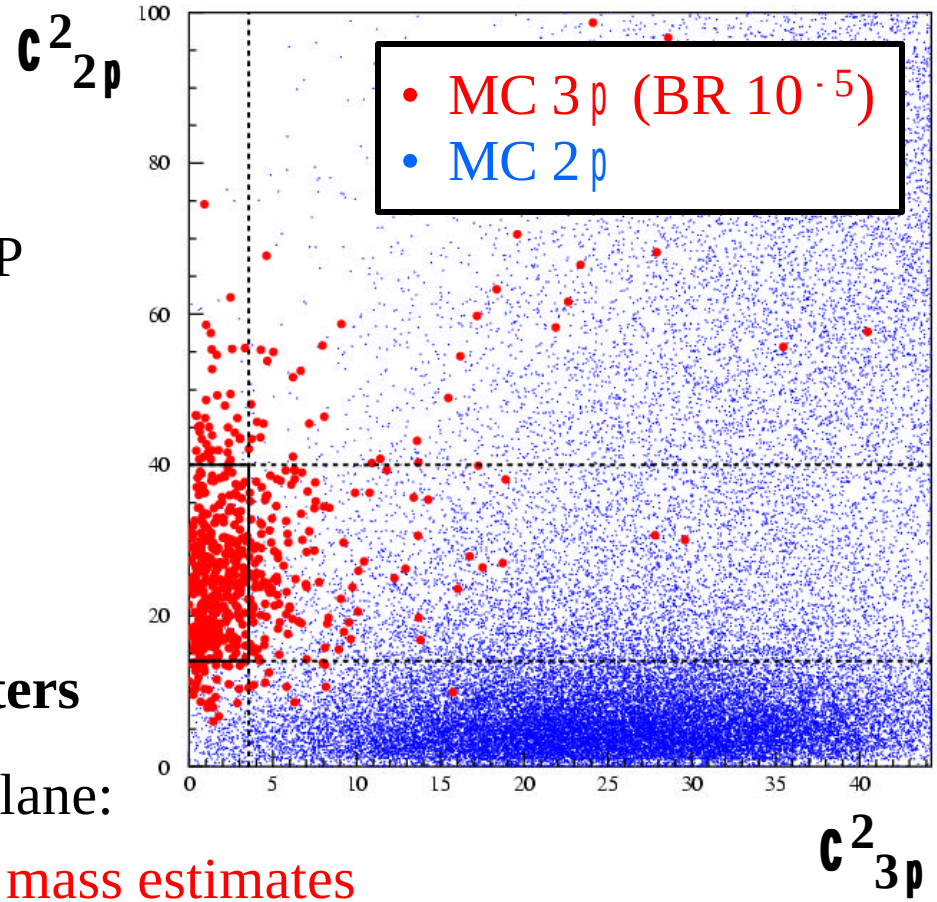
$|\mathrm{Im}\,\delta| < \sim 2 \times 10^{-5}$ $\Rightarrow$ $\dfrac{m_{K^0} - m_{\bar{K}^0}}{\langle m_K \rangle} < \sim 8 \times 10^{-19}$

Compare: $m_K/m_{\mathrm{Planck}} = 4 \times 10^{-20}$

Search for K_S ® $p^0 p^0 p^0$

Preselection:

- K_S tagged by K_L crash
- 6 photon clusters, no tracks from IP
- Kinematic fit to refine cluster parameters

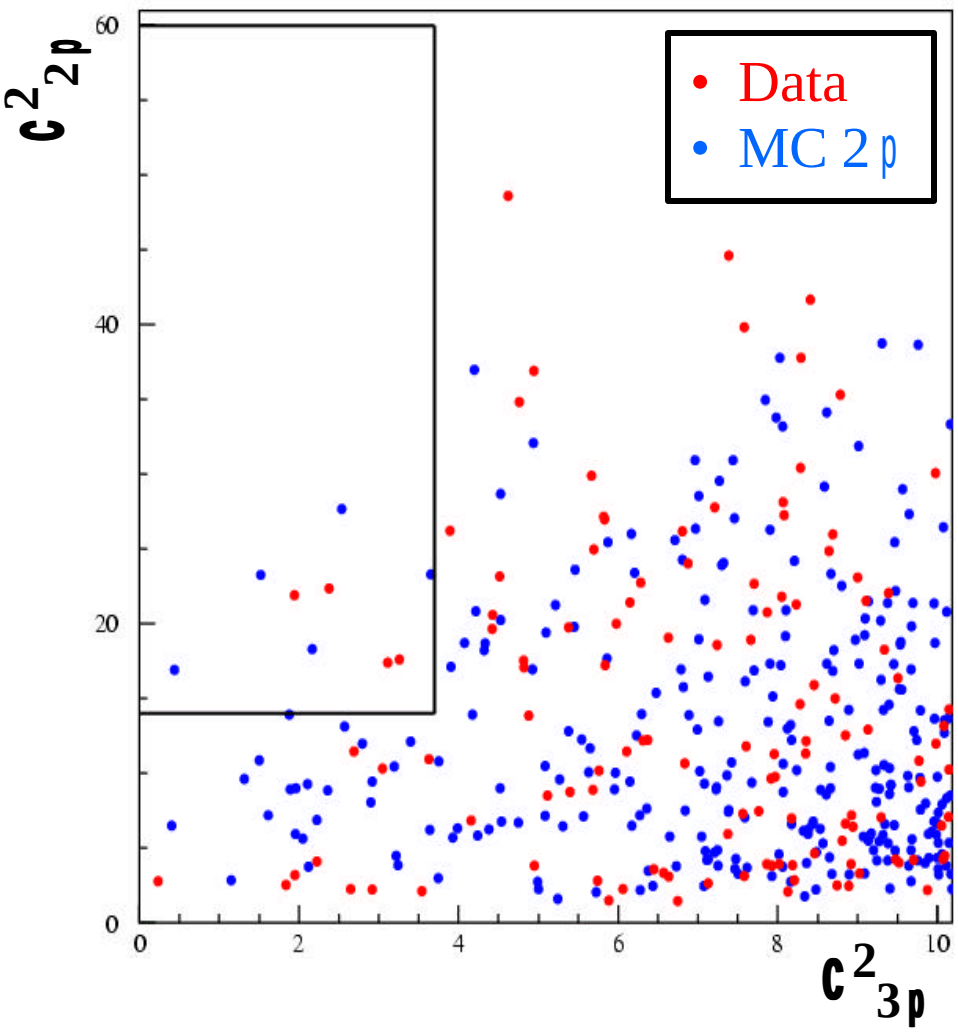


Rejection of background:

K_S ® $p^0 p^0$ + 2 split/accidental clusters

- Define signal box in c^2_{3p} vs. c^2_{2p} plane:
  - c^2_{3p} 3 cluster pairs with best p^0 mass estimates
  - c^2_{2p} pair 4 clusters using p^0 masses, $E(K_S)$, $\mathbf{p}(K_S)$, angle between p^0's
- Final cut on residual K_S energy: $E(K_S)$ · S E_p

Search for K_S ® $p^0 p^0 p^0$



Signal box optimized using dedicated MC subsample

e_{3p} = 22.6%
(events with K_L crash)

N_{bkg}(MC) = 3.2 ± 1.4 ± 0.5
Use N_{bkg}(expected) = 1.7 (· 1 s)

N_{obs} = 4

KLOE preliminary
450 pb^{-1} '01+'02 data

BR(K_S ® $p^0 p^0 p^0$)
£ 2.3 × 10^{-7} 90% CL

A word on $K_S \to \pi^+\pi^-\pi^0$

Branching ratio not well measured at present:

PDG Avg.	$\mathbf{3.2\ ^{+1.2}_{-1.0} \times 10^{-7}}$	[E621 '96, CPLEAR '97]
Phenomenology & χPT	$\mathbf{2.4 \pm 0.7 \times 10^{-7}}$	

$\eta_{+-0} = A[K_S \to (\pi^+\pi^-\pi^0)_{CP-}]/A[K_L \to \pi^+\pi^-\pi^0] \sim \eta_{000}$

CP– component extracted by integration over Dalitz plot, traditionally in interference measurements

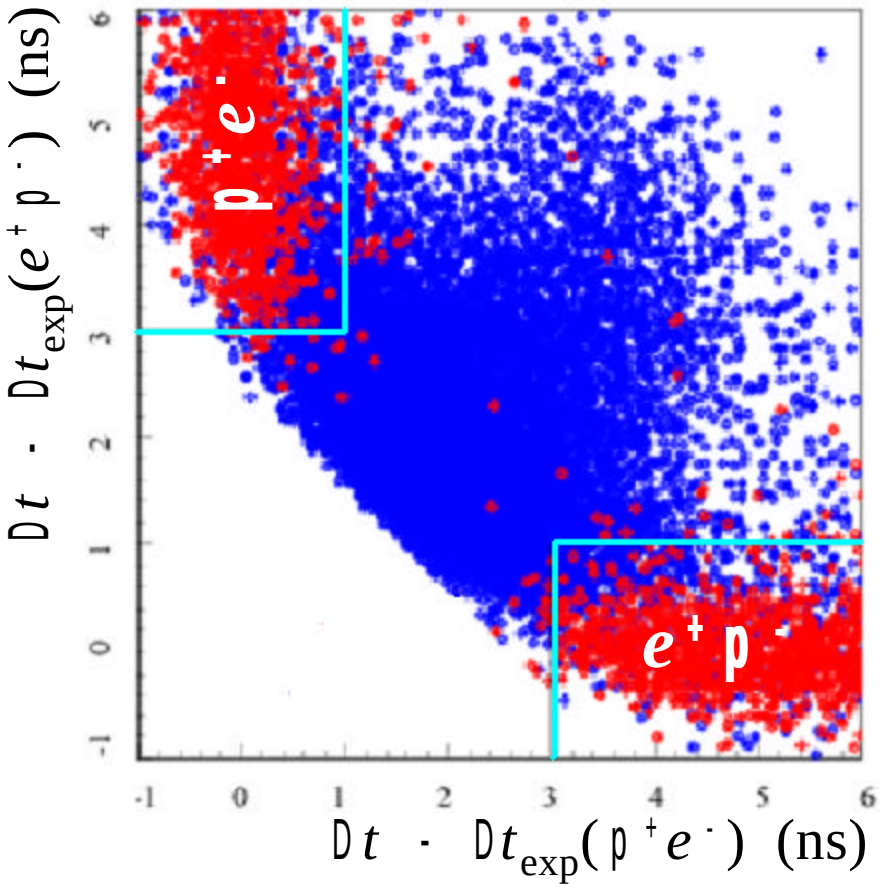
Feasibility studies indicate $\varepsilon \sim 5\%$ at KLOE (0.017 evts/pb^{-1})

450 pb^{-1} (~8 evts)	First **direct** measurement Competitive with existing measurements
2 fb^{-1} (~33 evts)	Measurement of BR($K_S \to \pi^+\pi^-\pi^0$) to < 20% • Comparison for χPT calculations of $\Delta I = 3/2$ amplitudes • First look at Dalitz-plot asymmetry

Analysis of K_S ® pen decays

2-track vertex at IP tagged by K_L crash

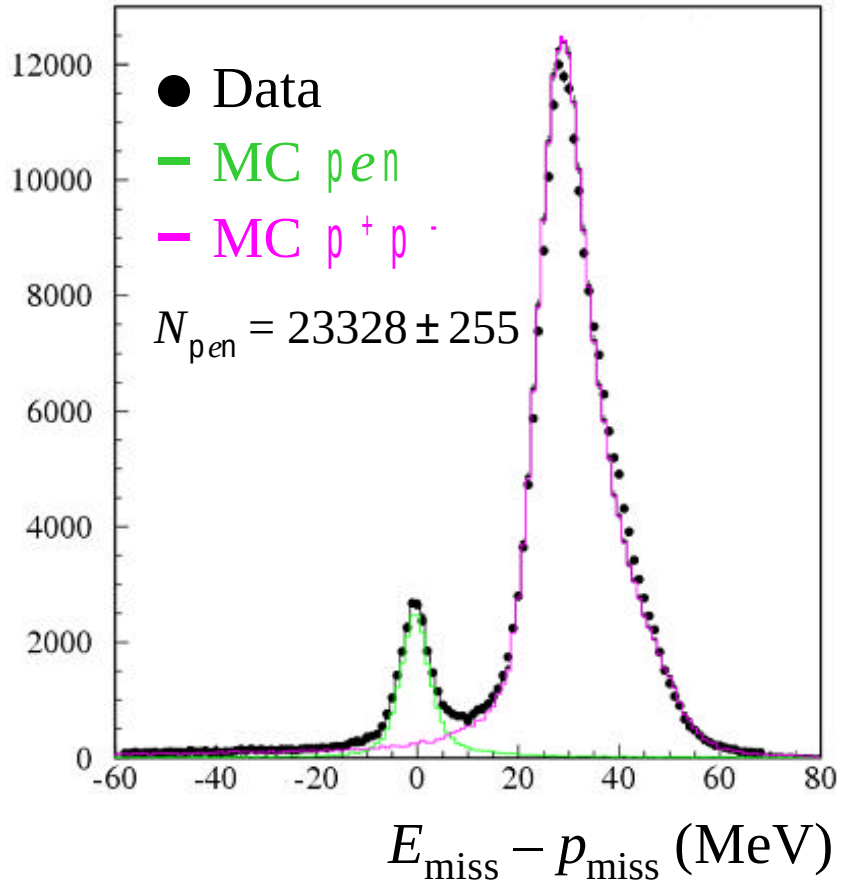
TOF PID from associated clusters



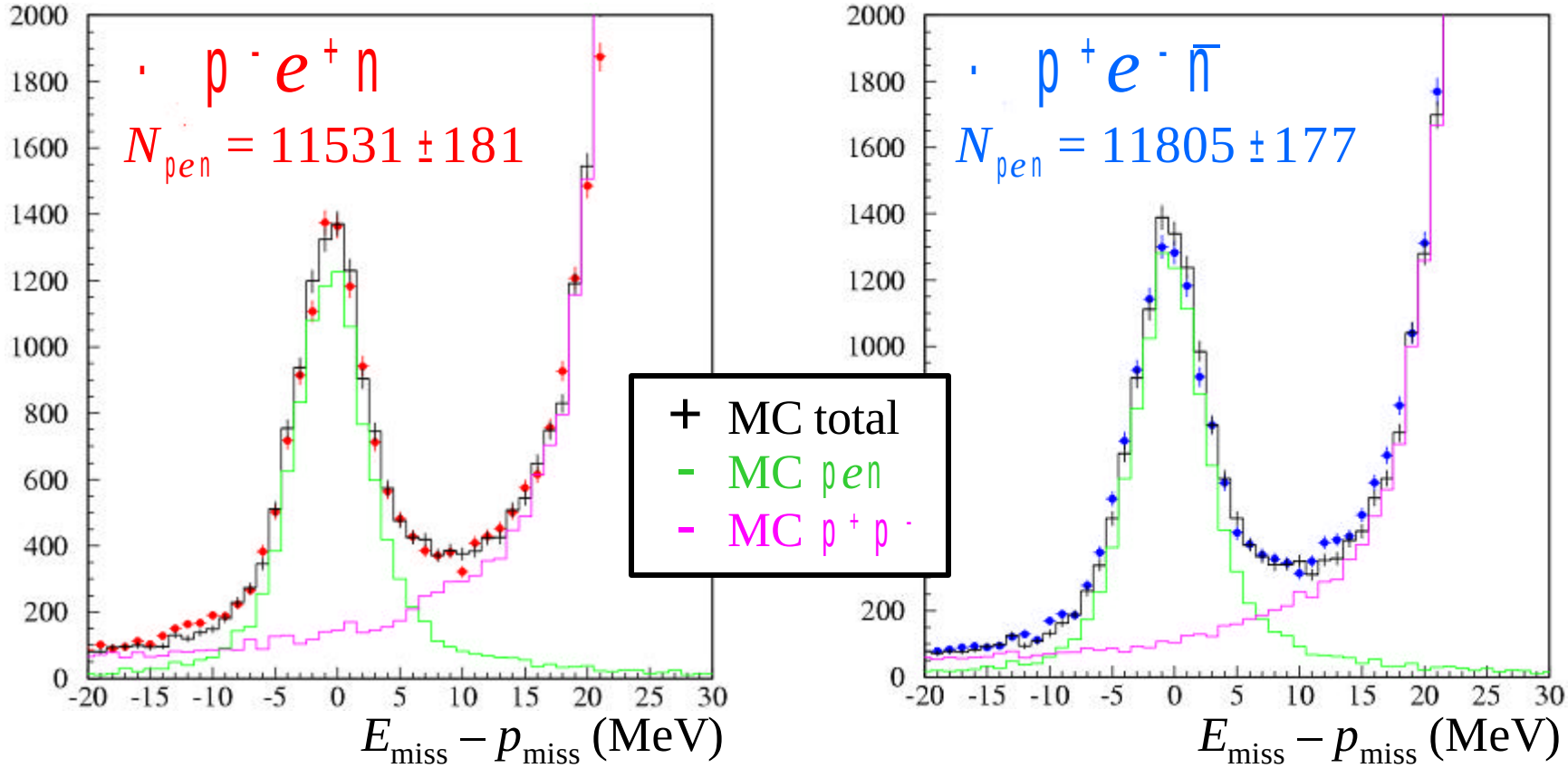
Close kinematics: $\boldsymbol{E}_{\mathbf{miss}} \cdot \boldsymbol{p}_{\mathbf{miss}} = \mathbf{0}$

Fit with MC spectra for pen and pp

MC includes radiative processes



$K_S \to \pi^- e^+ \nu,\ \pi^+ e^- \bar{\nu}$



KLOE preliminary

450 pb^{-1} '01+'02 data

Evaluation of systematic errors nearly complete

$BR(\pi^- e^+ \nu) = (3.54 \pm 0.05 \pm 0.05) \times 10^{-4}$

$BR(\pi^+ e^- \bar{\nu}) = (3.54 \pm 0.05 \pm 0.04) \times 10^{-4}$

$BR(\pi^\pm e^\pm \nu) = (7.09 \pm 0.07 \pm 0.08) \times 10^{-4}$

$K_S \to \pi e \nu$ decays – CP and CPT

$$A = \frac{\Gamma(\pi^- e^+ \nu) - \Gamma(\pi^+ e^- \bar{\nu})}{\Gamma(\pi^- e^+ \nu) + \Gamma(\pi^+ e^- \bar{\nu})} \quad \begin{cases} A_S = 2(\mathrm{Re}\,\epsilon + \mathrm{Re}\,\delta + \mathrm{Re}\,b/a - \mathrm{Re}\,d^*/a) \\ A_L = 2(\mathrm{Re}\,\epsilon - \mathrm{Re}\,\delta + \mathrm{Re}\,b/a + \mathrm{Re}\,d^*/a) \end{cases}$$

$\not{CP}$	$\not{CPT}$ in mixing	$\not{CPT}$ in decay	$\Delta S \neq \Delta Q$ and $\not{CPT}$

If *CPT* conserved, $A_S = 2\,\mathrm{Re}\,\epsilon$

$A_S - A_L \neq 0$ implies *CPT*

KLOE preliminary

$A_S = (-2 \pm 9 \pm 6) \times 10^{-3}$

First measurement of A_S!

Compare to results for A_L

KTeV $(3.322 \pm 0.058 \pm 0.047) \times 10^{-3}$

NA48 $(3.317 \pm 0.070 \pm 0.072) \times 10^{-3}$

With 2 fb^{-1}, KLOE can measure A_S to 4×10^{-3}

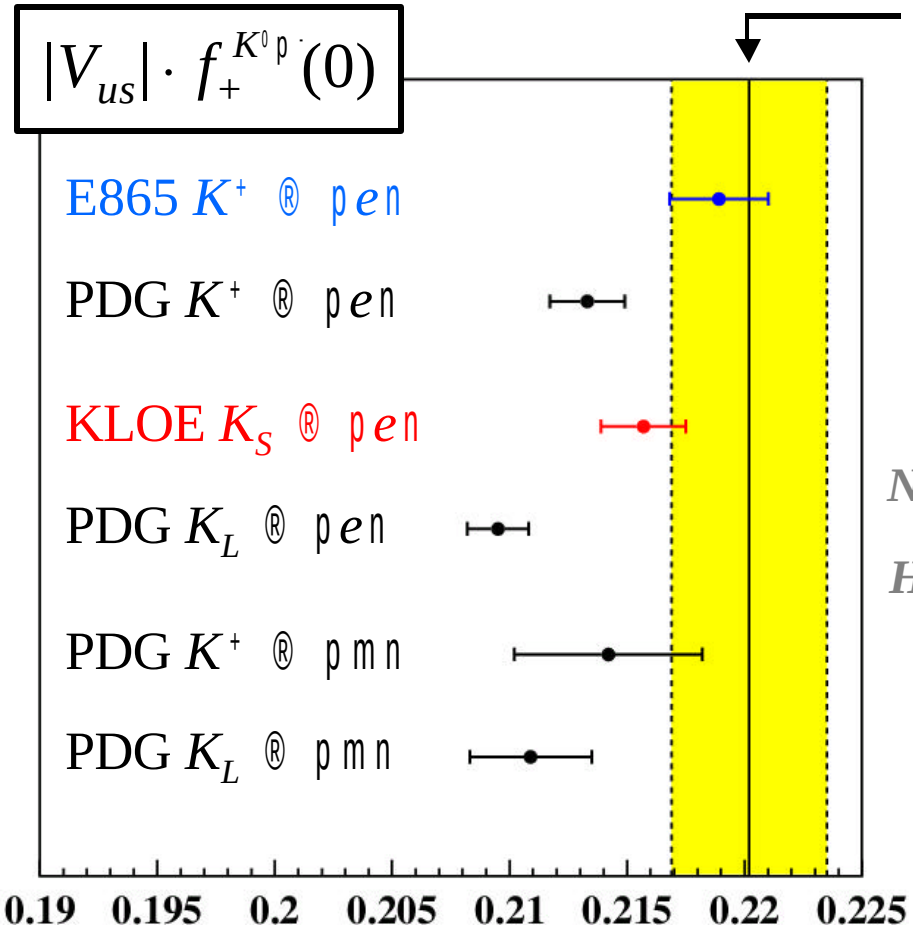
For competitive limit on *CPT* violation, need A_S to 1.5×10^{-3} @ 20 fb^{-1}

cf. CPLEAR '98 $\mathrm{Re}\,\delta = (3.0 \pm 3.4) \times 10^{-4}$

V_{us} from $K_{\ell 3}$ decays – CKM unitarity

Most precise test of CKM unitarity possible at present from 1st row:

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



Expected value assuming unitarity, $|V_{ud}|$ from superallowed 0^+ ® 0^+ Fermi transitions, neutron b-decays

To extract $|V_{us}|$ from K^0_{e3} decays:

$$\frac{d|V_{us}|}{|V_{us}|} = \frac{1}{2}\left(\frac{d\,\mathrm{BR}}{\mathrm{BR}}\right) \oplus \frac{1}{2}\left(\frac{dt}{t}\right) \oplus \frac{1}{20}\left(\frac{d\,l_+}{l_+}\right) \oplus \frac{df_+(0)}{f_+(0)}$$

Nominally: 0.5% 0.4% 0.4% 0.8%

exp th

However:

- K_{e3} BRs normalized using current PDG BR values (or ratios)
- Older measurements' inclusiveness of radiative processes uncertain
- Good values of t_+, t_L important

K_L decays – Present knowledge

Knowledge of 4 main K_L BRs currently dominated by 3 measurements:

$$\frac{\Gamma(K_L \to \pi^0\pi^0\pi^0)}{\Gamma(K_L \to \pi e \nu)} \text{ and } \frac{\Gamma(K_L \to \pi^0\pi^0\pi^0)}{\Gamma(K_L \to \pi^+\pi^-\pi^0)}, \text{ with } \sim 2\% \text{ relative uncertainty}$$

[NA31 '95]

$$R_{\mu/e} \equiv \frac{\Gamma(K_L \to \pi \mu \nu)}{\Gamma(K_L \to \pi e \nu)} = 0.697 \pm 0.010 \quad \text{[Argonne HBC '80]}$$

4% discrepancy between measurement and expectation for $R_{\mu/e}$:

$R_{\mu/e} = 0.671 \pm 0.011$ direct measurement for K^+ [KEK-E246 '01]

$R_{\mu/e}$ calculable from slopes λ_+ and λ_0 of vector and scalar form factors:

0.670 ± 0.002 if $\lambda_0 = 0.0183 \pm 0.0013$ [ISTRA+ '04]

0.668 ± 0.006 if $\lambda_0 = 0.017 \pm 0.004$, from one-loop χPT

K_L decays – Status and objectives

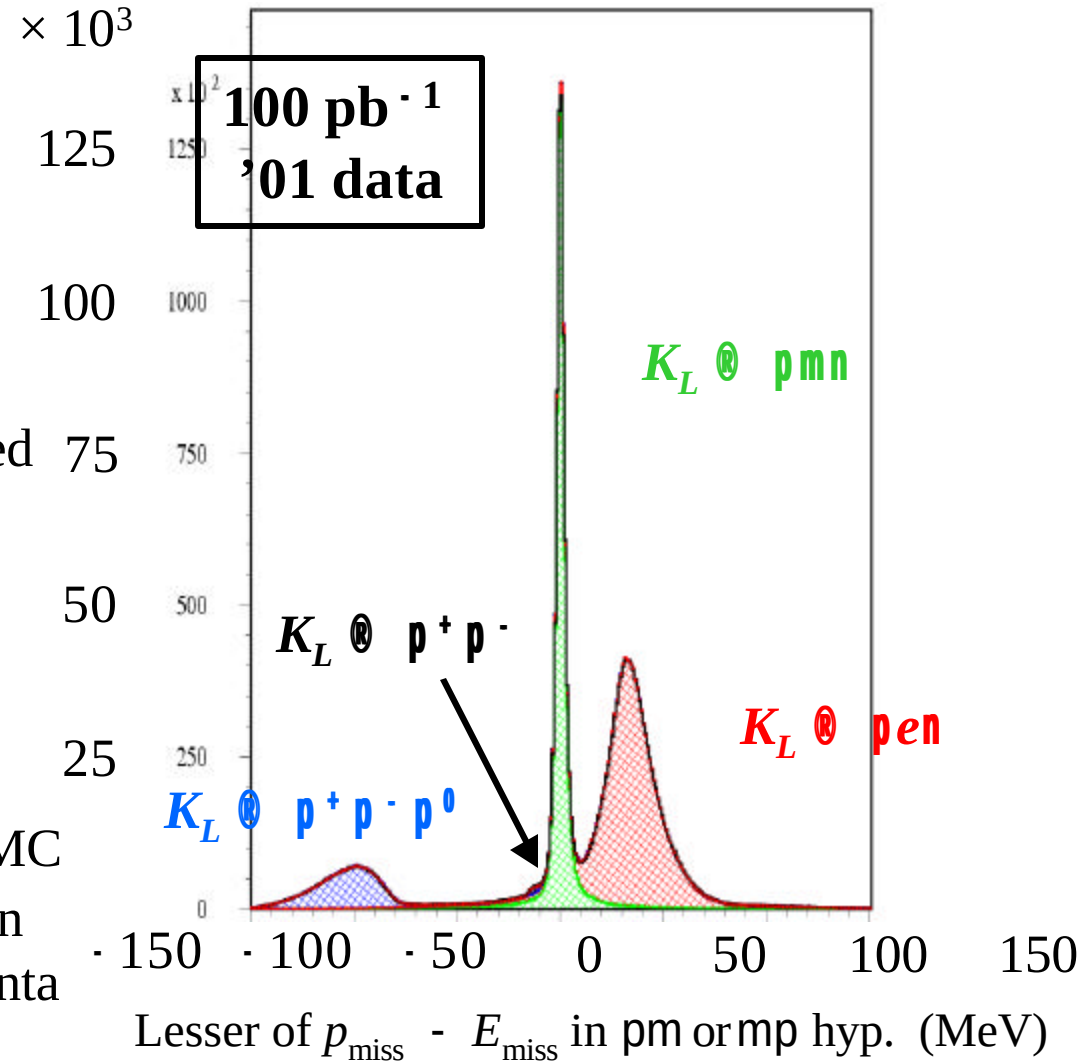
Precisely measure absolute branching ratios to □ 1%

- K_L beam tagged by K_S ® p+p-
- K_L vertex reconstructed in DC
- PID using decay kinematics
- Fit with MC spectra including radiative processes and optimized EmC response to m/p/K_L

450 pb-1 = 3 × 10^6 K_L ® pen events detected

In progress:

- Analysis with newly upgraded MC
- Selection efficiency as a function of K_L vertex position and momenta of decay products



Mean life of the K_L

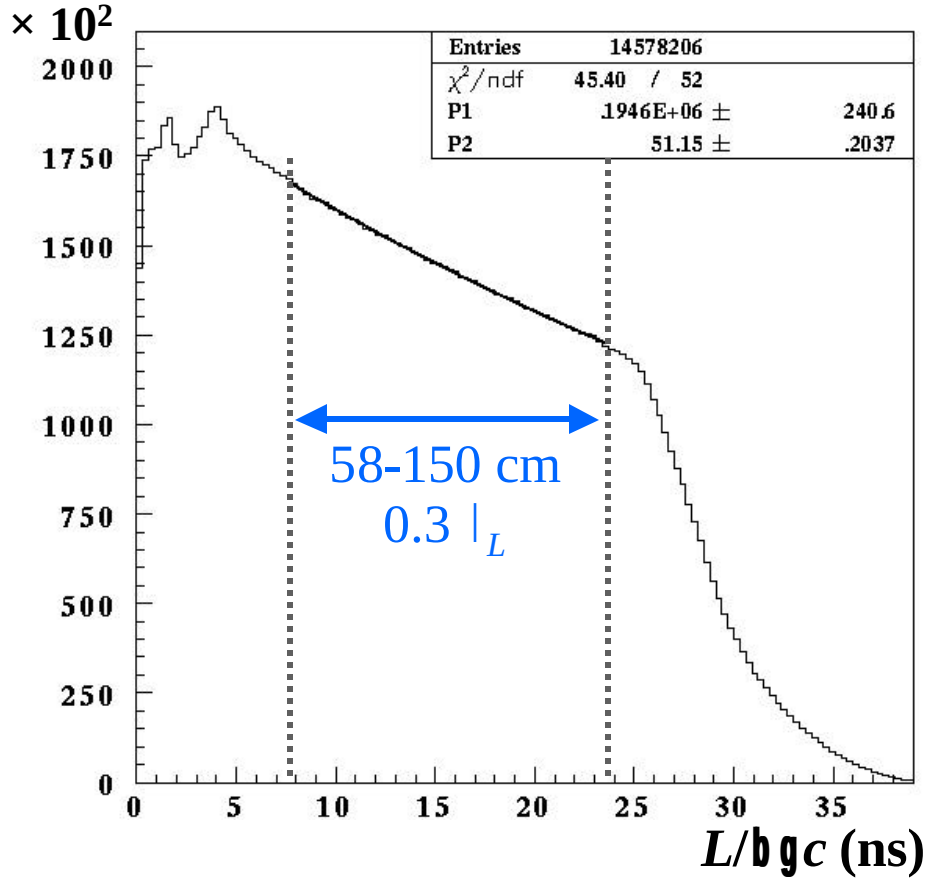
K_L mean life "hard" to measure

- Can't stop K_L's!
- High K_L momentum at fixed-target setups means limited lever arm

	$\beta\gamma$	FV
NA48	220	$0.03\ \lambda_L$
KLOE	0.22	$0.3\ \lambda_L$

Using $K_L \to \pi^0\pi^0\pi^0$

- Require $\geq$ 3 γ's $\to \epsilon(L_K)$ uniform
- $\sigma_L(\gamma\gamma) \sim 2$ cm



Very preliminary
Stat. error only

PDG avg. (Vosburg, '72): $\tau_L = 51.5 \pm 0.4$ ns

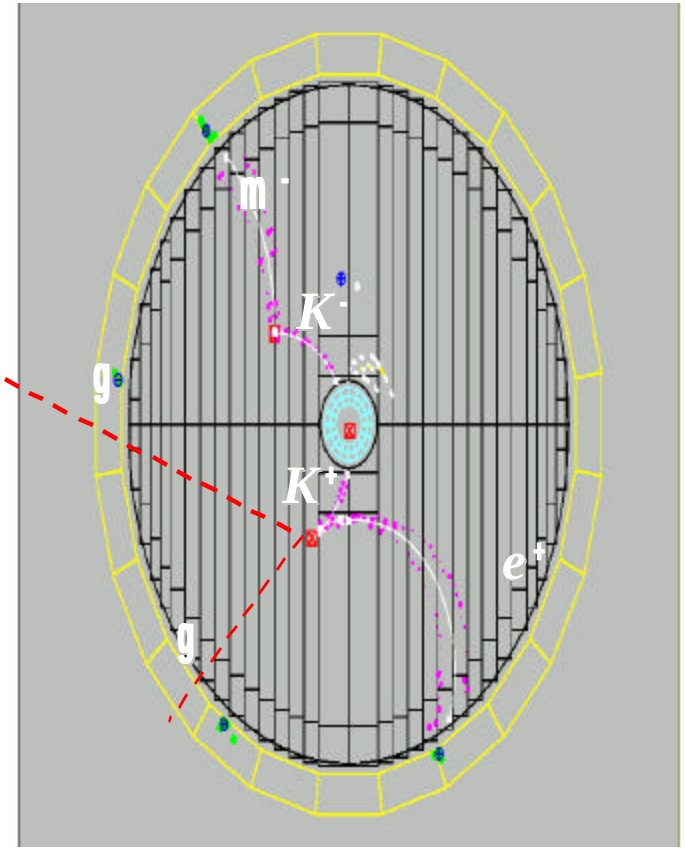
KLOE 440 pb^{-1}: $\tau_L = 51.15 \pm 0.20_{stat}$ **ns**

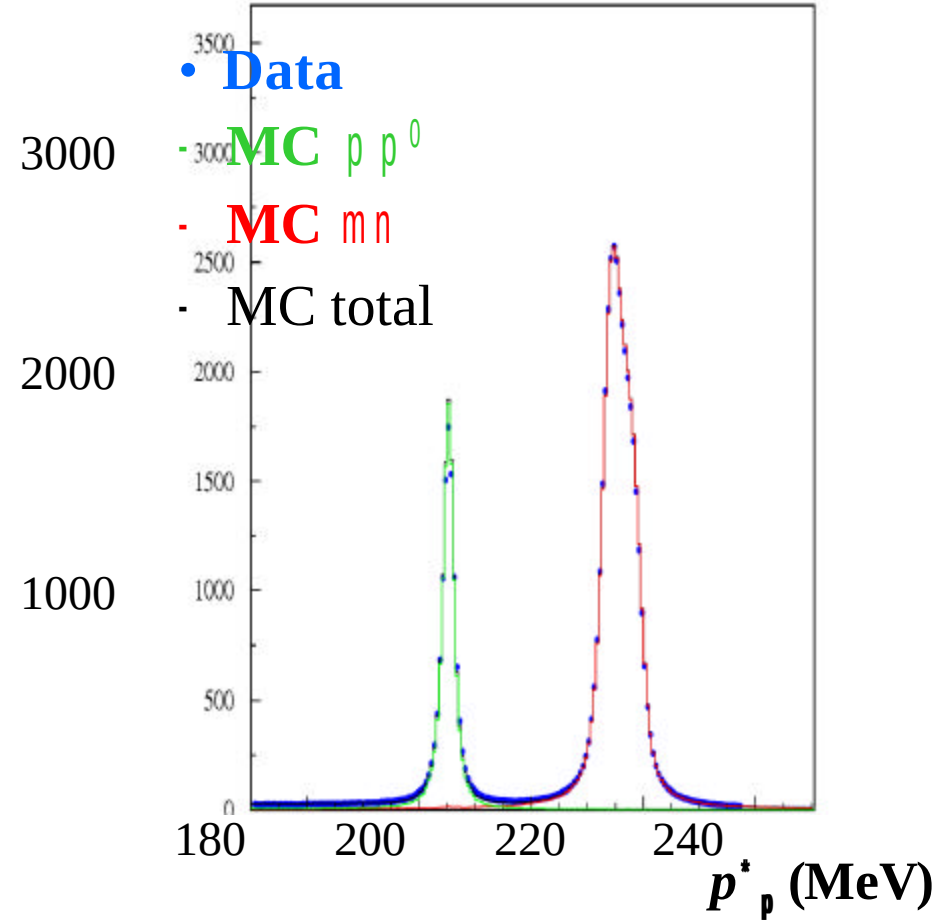
14.5M $K_L \to \pi^0\pi^0\pi^0$ evts

Charged kaons – tagging

Tagging via $K \to \mu\nu$ or $K \to \pi\pi^0$

6×10^5 tags/pb^{-1} for measurement of absolute BR's





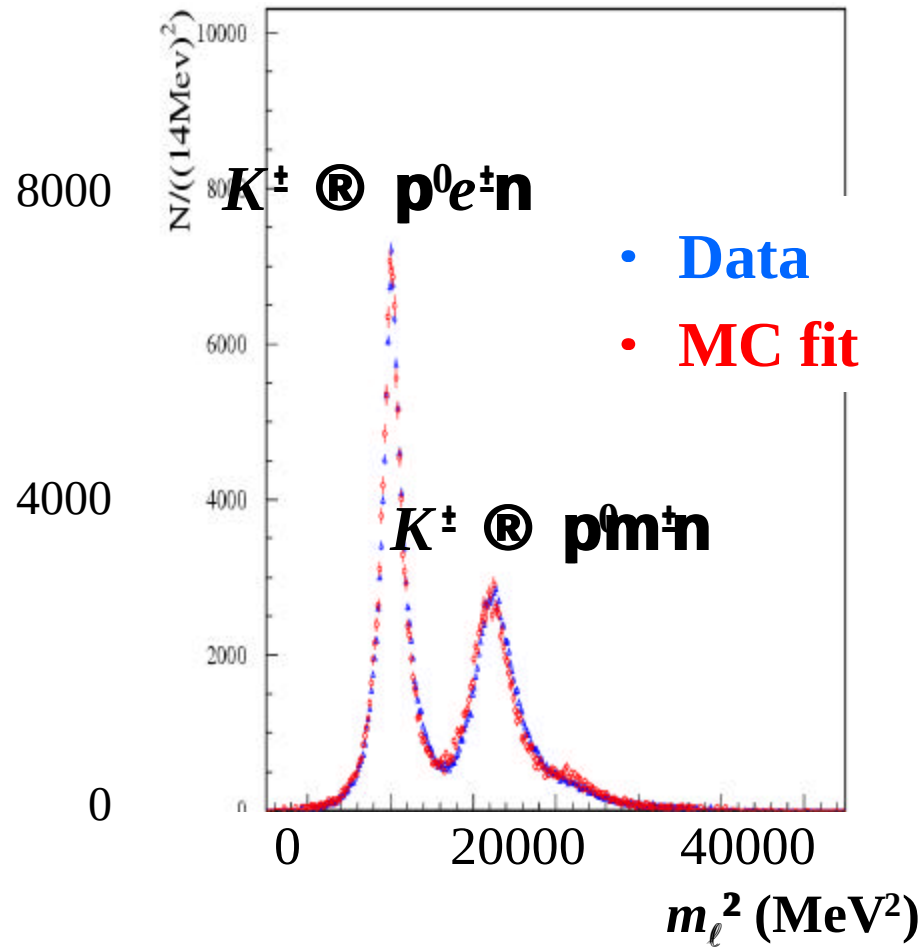
Charged kaons – $K^{\pm}_{\ell 3}$ decays

Measure $K_{\ell 3}$ BRs to □ 1%

- Reconstruct decay vertex in DC
- Reject $K \to \pi \pi^0$ and $\mu\nu$ by cut on p^*_π
- Require 2 γ clusters in EmC with TOF consistent with DC vertex position
- Obtain charged-daughter mass spectrum from TOF measurement:

$$\beta_\gamma c = \frac{L_\ell}{t_\ell - t_\gamma + L_\gamma/c}$$

450 pb^{-1} → 3 × 10^5 $K^{\pm}_{e3}$ events



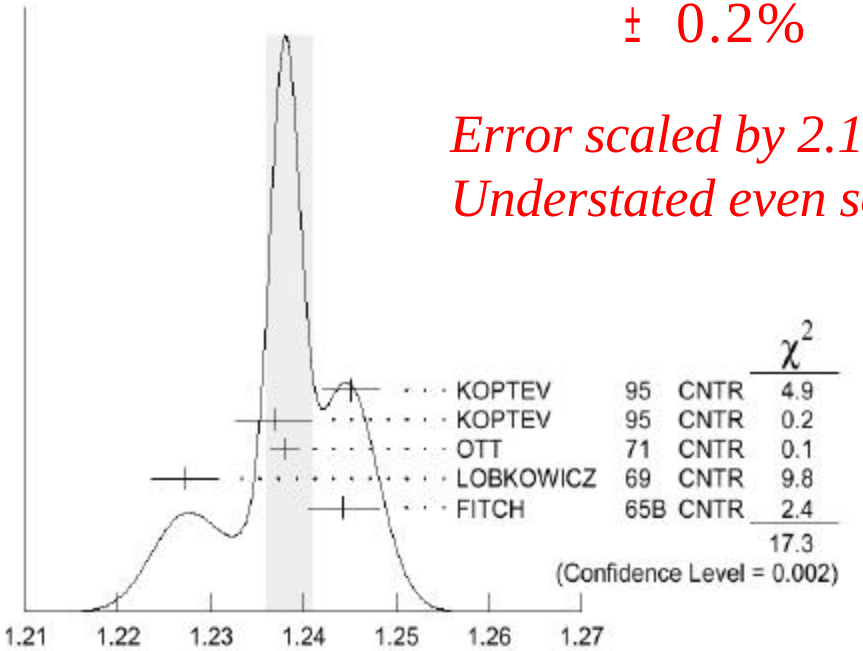
In progress:

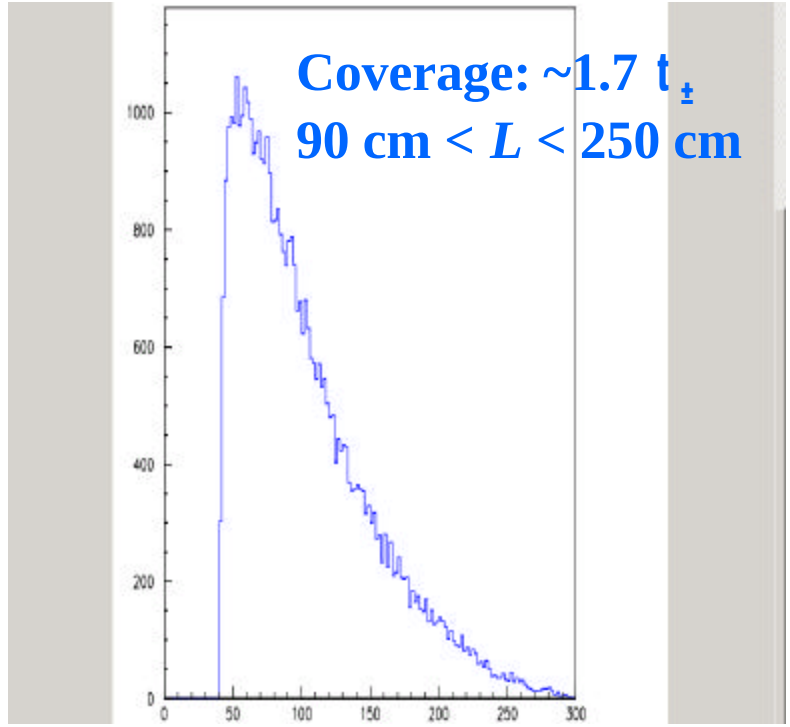
- Evaluation of selection bias due to interference from tagging decay
- Analysis with MC upgrade (radiative processes, optimized EmC response to π/μ)

Mean life of the $K^{\pm}$

PDG avg. $\tau_{\pm}$ = 12.385 ± 0.025 ns
± 0.2%

Error scaled by 2.1
Understated even so?





Tag with $K \to \mu\nu$

Measure L from $K \to \pi\pi^0$ vertex

$\sigma_L(K\pi)$ = 3 mm

450 pb^{-1} @ 70 × 10^6 events

Measure decay time independently with $\pi^0 \to \gamma\gamma$ vertex:

$\sigma_L(\gamma\gamma)$ = 3 mm (after kinematic fit)

Also useful for efficiency studies

Reprise: KLOE in 2004

Present status:

- Sensitivity to K_S BRs at 10^{-7} level (preliminary UL for $K_S \to 3\pi^0$)
- Measurement of BR($K_S \to \pi e \nu$) mode at the % level, A_S to 10^{-2}
- Measurements of BRs for semileptonic K_L and $K^{\pm}$ decays in progress

Data taking restarted 27 April

Currently, $L_{peak} = 4 \times 10^{31}$ cm^{-2} s^{-1}

$L_{avg} > 10^{32}$ cm^{-2} s^{-1} expected after tuning

Expect 2 fb^{-1} of integrated luminosity in 2004, will allow:

- A_S with a total accuracy of 4×10^{-3}, first test of SM prediction $A_S = 2\,\mathrm{Re}\,\epsilon$
- Limit on BR($K_S \to 3\pi^0$) at 10^{-8} level, BR($K_S \to \pi^+\pi^-\pi^0$) to 20%
- ***First studies of CP/CPT parameters of $K_S K_L$ system via interference***

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

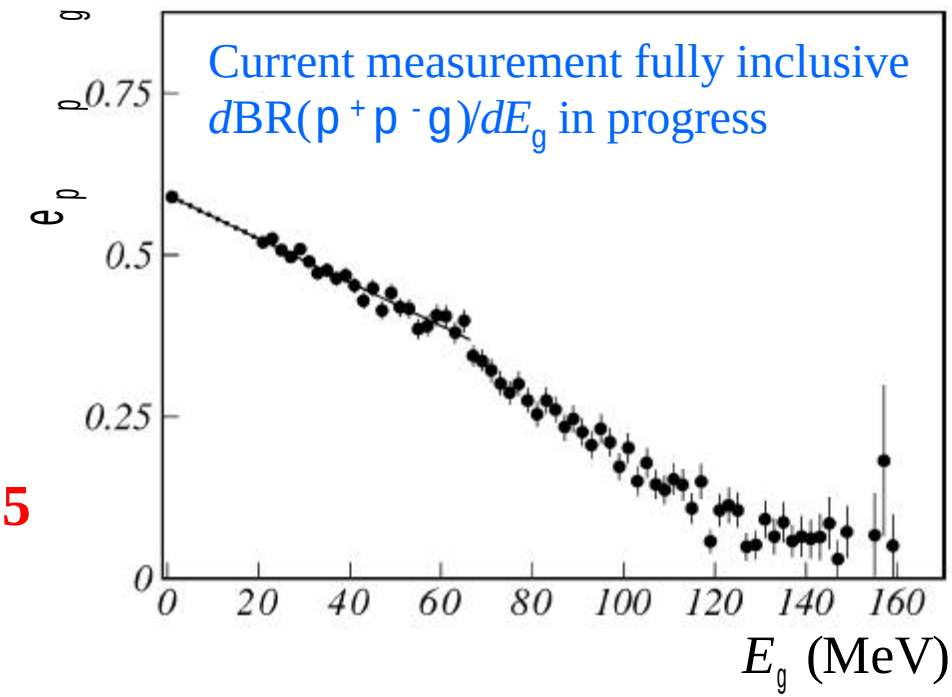
- First part of double ratio for Re ϵ'/ϵ
- Provides information on EM isospin breaking in $K \to \pi\pi$ decays
- Can extract $\delta_0 - \delta_2$ if effective E_γ cutoff known for $\pi\pi\gamma$ channel

PDG '02 **2.197 ± 0.026 (avg.)**

KLOE '02 **2.236 ± 0.003 ± 0.015**

17 pb^{-1} '00 data, *Phys. Lett.* **B538** 21

Error will be reduced to 0.1%



$\delta_0 - \delta_2$		$\delta_0 - \delta_2$	
PDG widths Cirigliano et al. '01	**(56 ± 8)°**	**(45 ± 6)°**	χPT estimate Gasser & Meissner, '91
KLOE '02 value for $\Gamma(\pi^+\pi^-)/\Gamma(\pi^0\pi^0)$	**(48 ± 3)°**	**(47.7 ± 1.5)°**	$\pi\pi$ scattering Colangelo et al. '01

Prospects for e¢/e

$$1 - 6\,\mathrm{Re}\,\epsilon'/\epsilon = \frac{BR(K_S \to \pi^+\pi^-)}{BR(K_S \to \pi^0\pi^0)} \cdot \frac{BR(K_L \to \pi^0\pi^0)}{BR(K_L \to \pi^+\pi^-)}$$

K_S

Statistical error: ***negligible***

Systematic error:

Source	**Error (%)**
Tagging	0.55 ('00 data) ® ~0.1 ('01-02 data)
g counting	0.20
Trigger/t_0	0.23
Tracking	0.26

Total error: 0.7% ® 0.4%

Will scale down to ~0.1% on full data set (~450 pb^{-1})

K_L

Statistical error: ~1.5%

Systematic error: ~1%, *in progress*

$\pi^+\pi^-$

- Momentum reconstruction/resolution, including DC occupancy effects
- Effect of $K\ell 3\gamma$ decays on background determination

$\pi^0\pi^0$

- Separation of overlapping clusters
- Regeneration

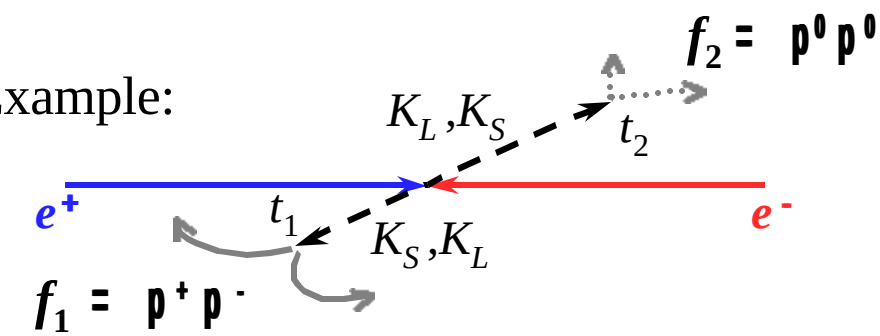
Need at least 10´ more data to reach the sub-10^{-3} level for Re e¢/e

CP/CPT studies: longer term prospects

Interference term in $I(\Delta t\,|f_1, f_2) \propto -2|h_1||h_2|e^{-\frac{\Gamma\Delta t}{2}}\cos(\Delta m\Delta t + f_2 - f_1)$

$$h_f = |h_f|e^{if_f} = \frac{A(K_L \to f)}{A(K_S \to f)}$$

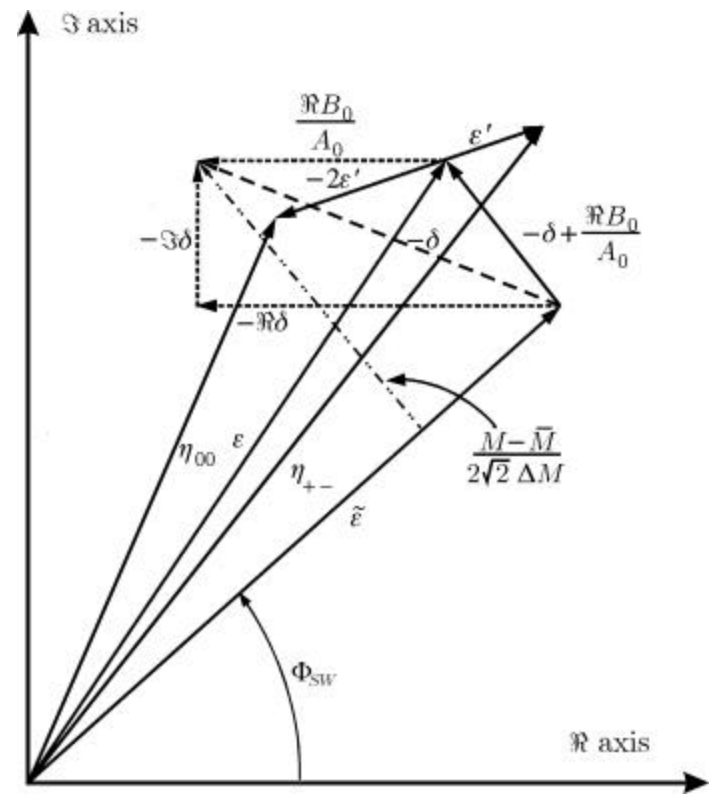
Example:



h_1 → $h_{+-} \approx e + e¢$

h_2 → $h_{00} \approx e - 2e¢$

$f_1 - f_2$ → $f_{+-} - f_{00} \approx 3\,\mathrm{Im}\, e¢/e$



With sufficient *L*, KLOE can use both absolute BR measurements and interferometry to measure many *CP* & *CPT* violation parameters of $K_S K_L$ system

A first glance at interference

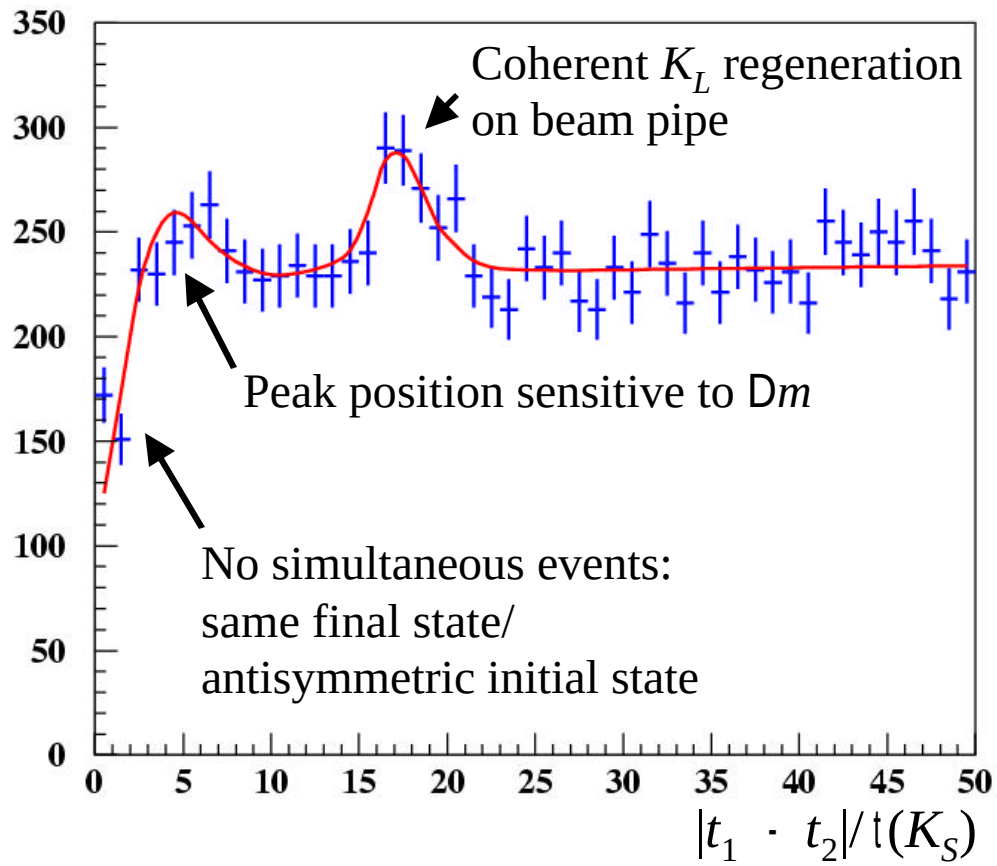
$K_S K_L \to \pi^+\pi^-\pi^+\pi^-$: $\quad |A(\Delta t)|^2 \propto e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2e^{-(\Gamma_S+\Gamma_L)|\Delta t|/2}\cos(\Delta m \Delta t)$

KLOE preliminary
340 pb^{-1} '01 + '02 data

Fit with PDG values for Γ_S, Γ_L
χ^2/d.o.f. = 43.7/47

Δm = (5.64 ± 0.37)×10^9 $\hbar$ s^{-1}
PDG '02: (5.301 ± 0.016)×10^9 $\hbar$ s^{-1}

First observation of quantum interference in relative decay-time distribution of K_S, K_L



Why $K \to \pi\nu\nu$ is out of reach

Estimates based on $\mathcal{L} = 10^{35}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
1000 fb^{-1}/yr

Total $\int \mathcal{L}\, dt = 2000\ \mathrm{fb}^{-1}$
2×10^{12} $K_S K_L$ pairs
6×10^{12} $K^{\pm}$ decays

$K_L \to \pi^0\nu\nu$

$BR_{SM} = (2.8 \pm 1.0) \times 10^{-11}$

Events produced	56
—tagged, ϵ = 70%	39
—with K_L in FV, ϵ = 30%	13
—selected, ϵ = 10%	**1.3**

$K^{\pm} \to \pi^{\pm}\nu\nu$

$BR_{SM} = (7.2 \pm 2.1) \times 10^{-11}$

Events produced	430
—tagged, ϵ = 20%	86
—with $K^{\pm}$ in FV, ϵ = 60%	52
—selected, ϵ = 10%	**5.2**

$\mathcal{L} = 10^{35}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ and ϵ_{sel} = 10% "aggressively" optimistic

Not competitive with hadron machines in any case

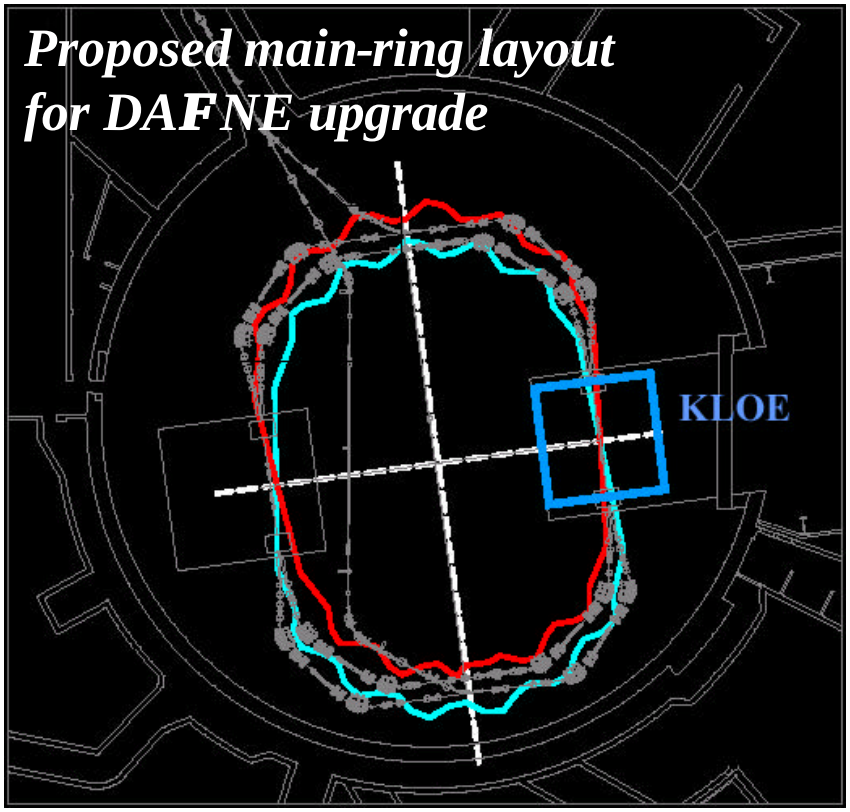
DAΦNE and KLOE: future upgrades

Next-generation DAΦNE ($\sqrt{s} = m_\phi$) with L up to 5×10^{34} cm^{-2} s^{-1} would allow competitive measurements of

- Rare K_S decays
- CP/CPT parameters via $K_S K_L$ interference

Would require a KLOE upgrade:

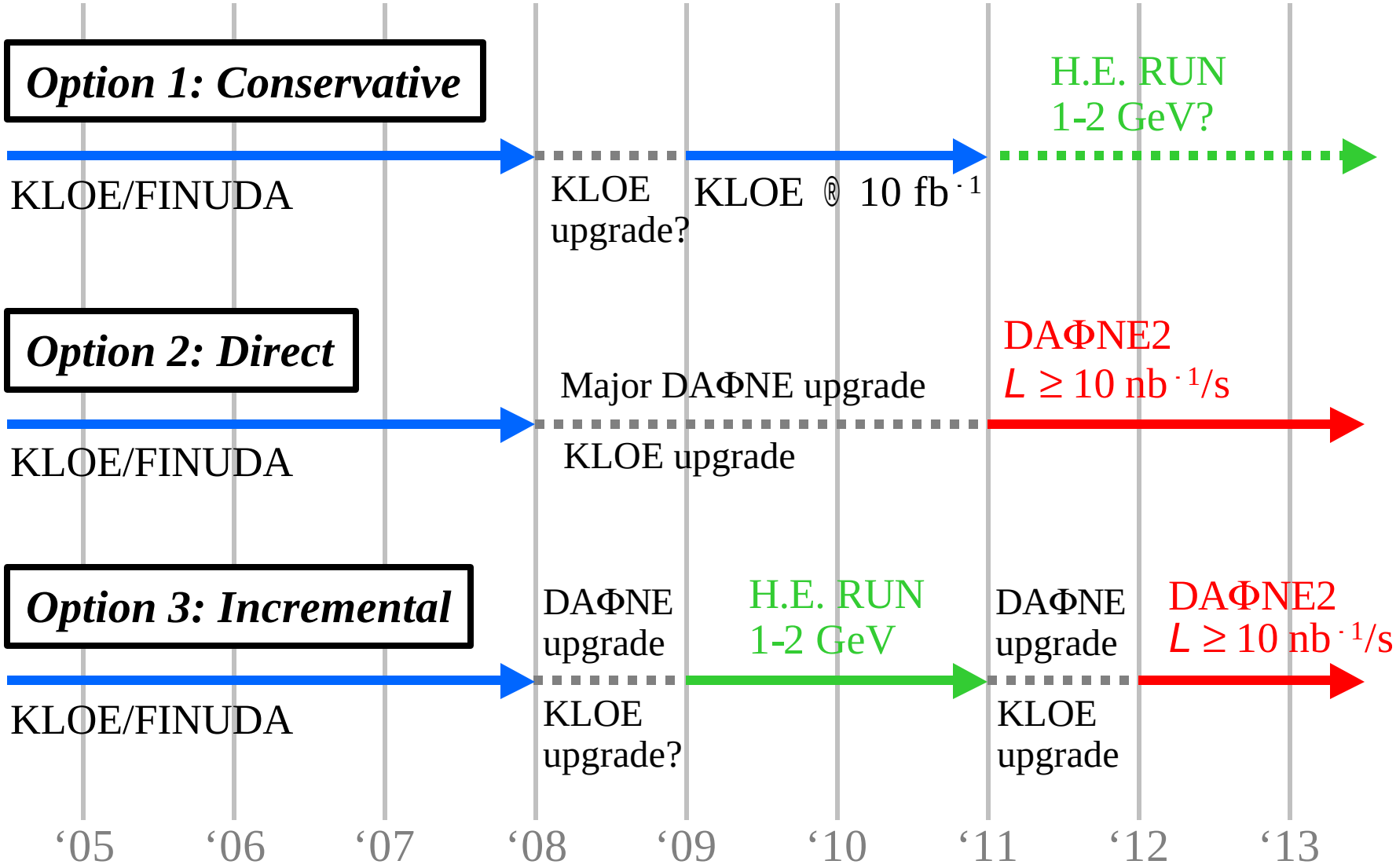
- Vertex detector!
- New DC: higher segmentation (possibly smaller)
- Upgrade to EmC: added depth, higher readout granularity



Proposed main-ring layout for DAΦNE upgrade

Currently moving from discussion to proposal stage

DAFNE upgrade scenarios



Kaon physics with KLOE: summary

KLOE is analyzing a unique data sample: 450 pb^{-1} of ϕ decays

- Lowest limit on BR($K_S \to 3\pi^0$)
- First measurement of the K_S semileptonic asymmetry
- Measurements of K_L, $K^{\pm}$ branching ratios, V_{us} forthcoming

KLOE expects to collect 2 fb^{-1} in 2004-2005

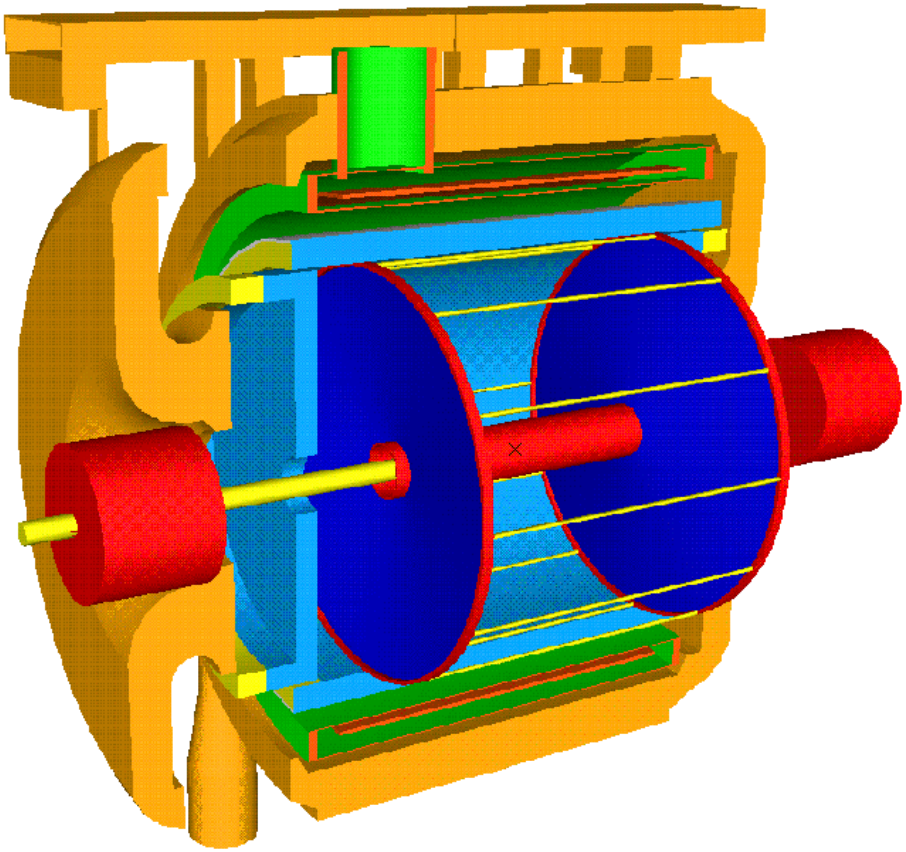
Will begin to exploit KLOE's capability for *CP*/*CPT* measurements

- Limit on $K_S \to 3\pi^0$ at the 10^{-8} level
- K_S semileptonic asymmetry to 4×10^{-3}
- First studies of $K_S K_L$ system with interference

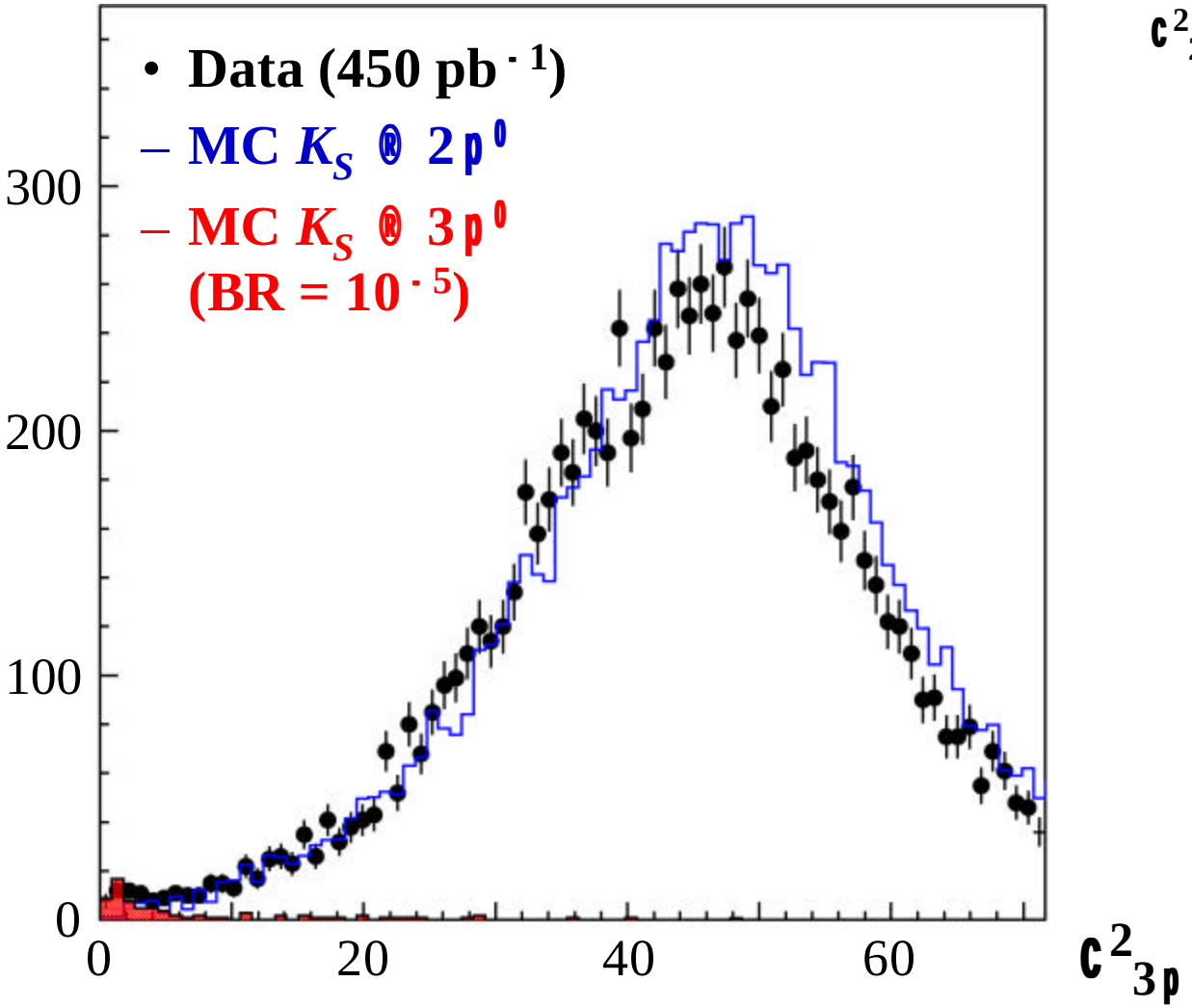
A feasible and competitive program exists for a ϕ factory with $L \gg 10^{33}$-10^{34} cm^{-2} s^{-1}

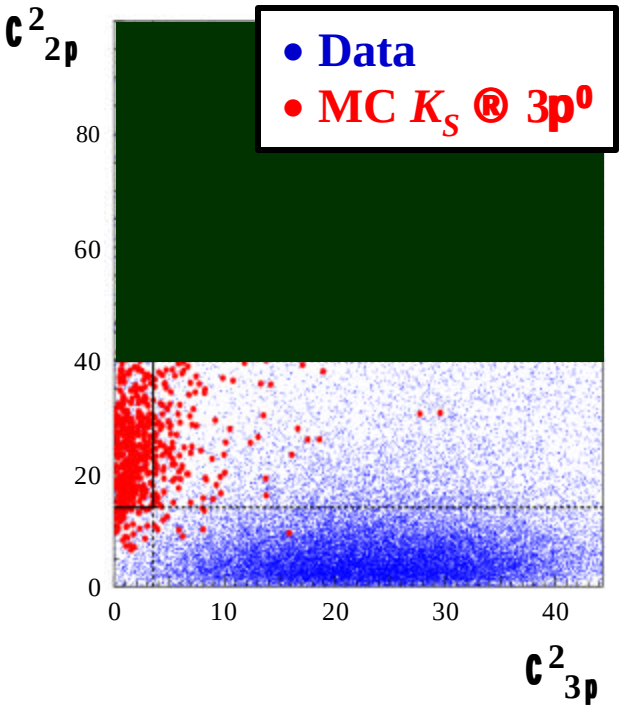
- Precise measurements of rare K_S decays
- Comprehensive survey of *CP*/*CPT* violation in $K_S K_L$ system via interference

Additional information

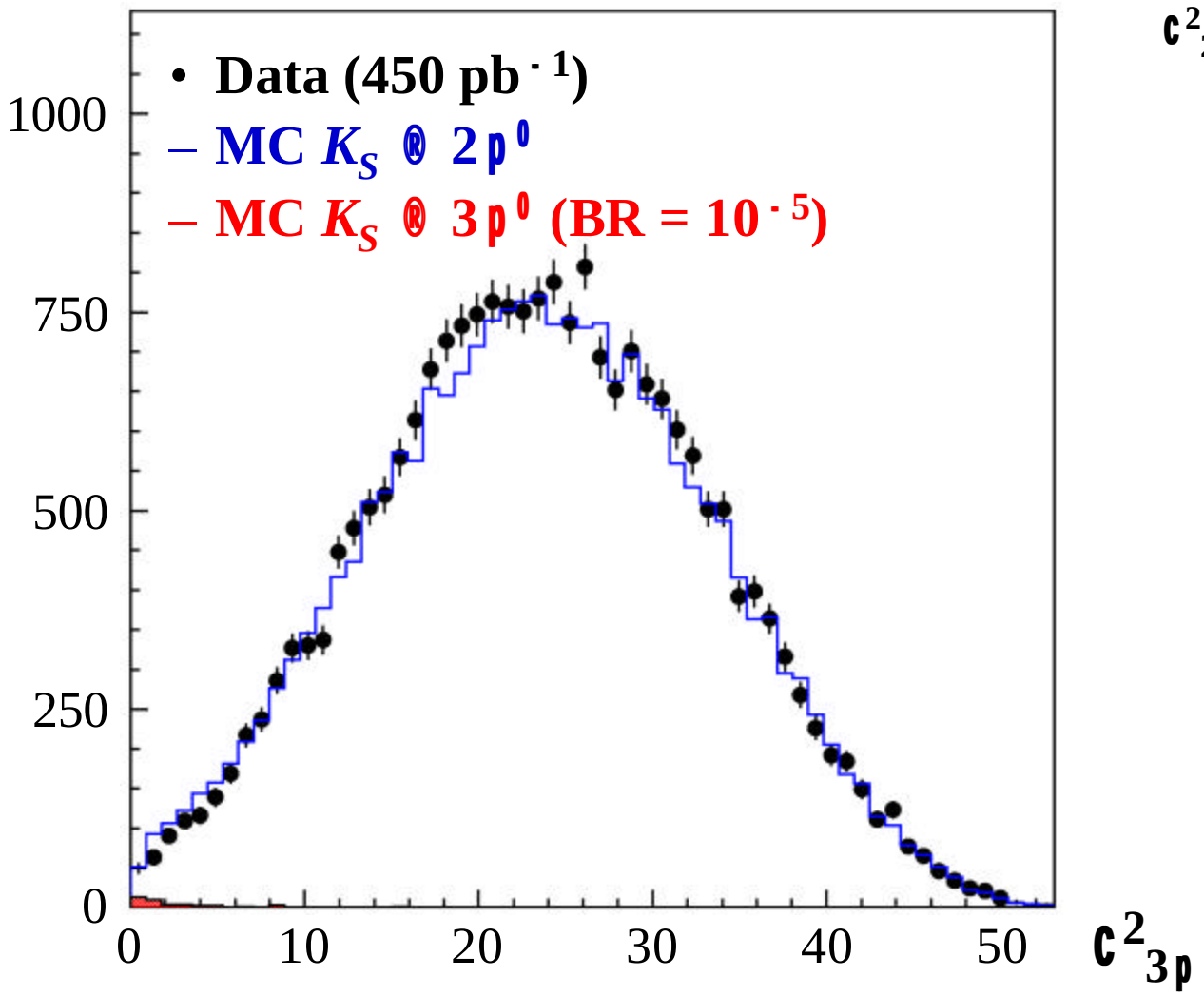


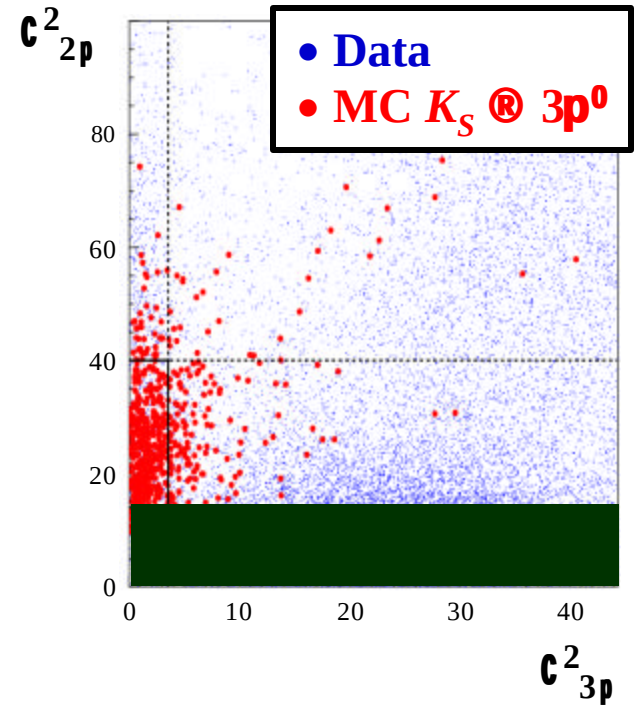
Search for K_S ® $p^0 p^0 p^0$ – sidebands



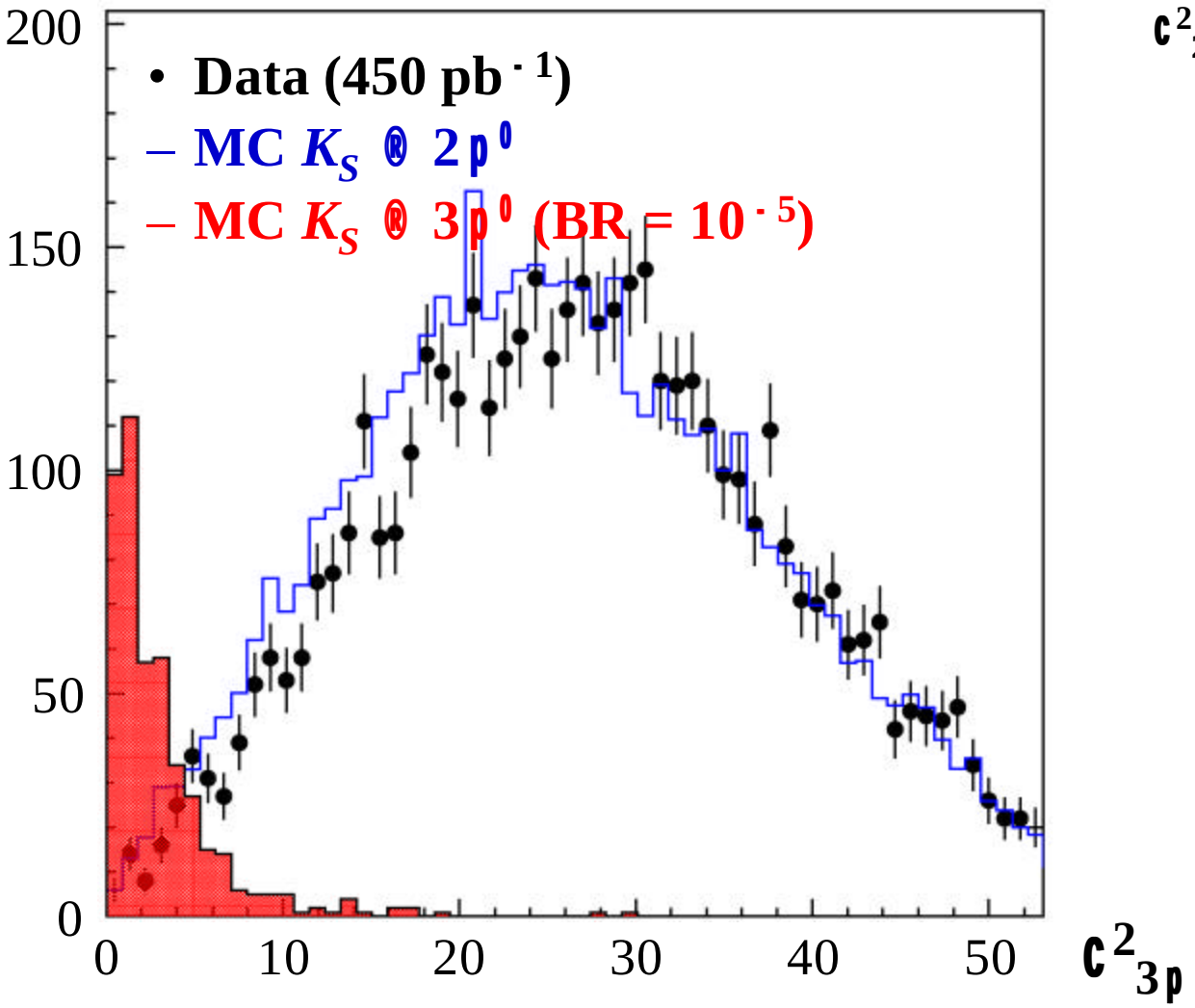


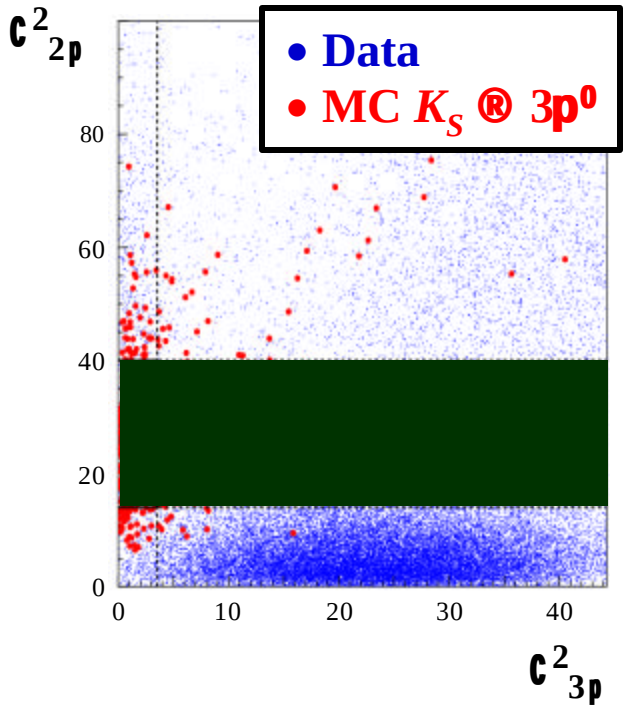
Search for K_S ® $p^0 p^0 p^0$ – sidebands





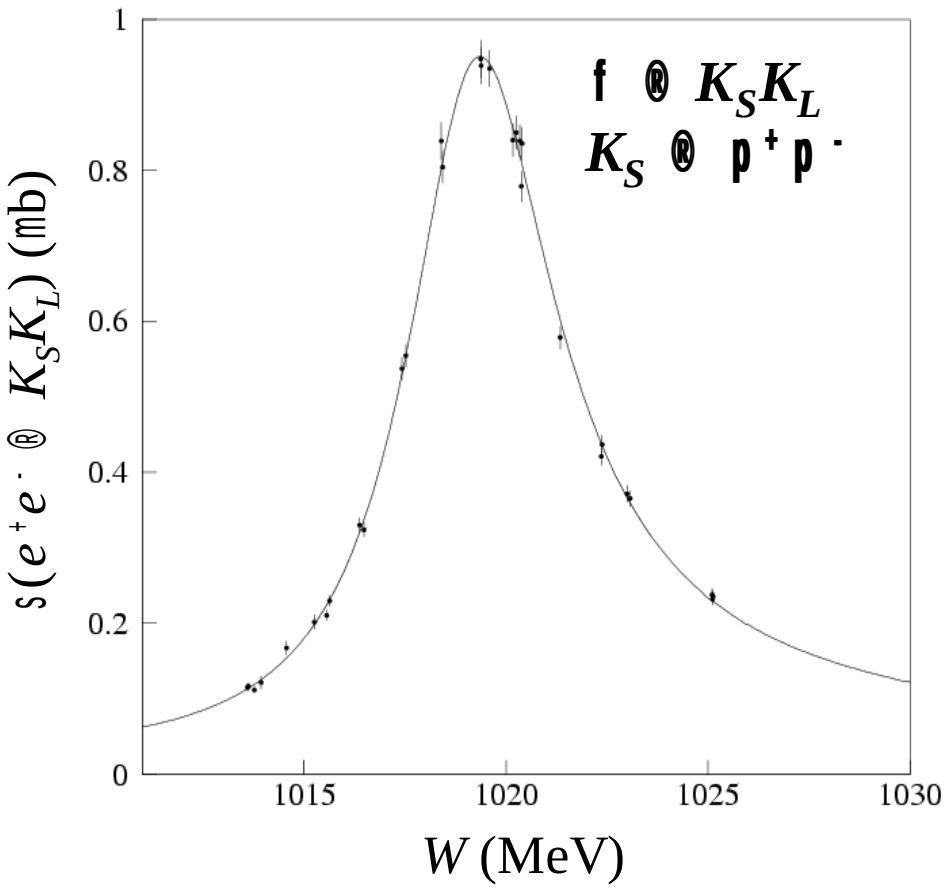
Search for K_S ® $p^0 p^0 p^0$ – sidebands





Measurement of K_S mass

2001 f peak scan: 29 pts, 0.5 pb^{-1}

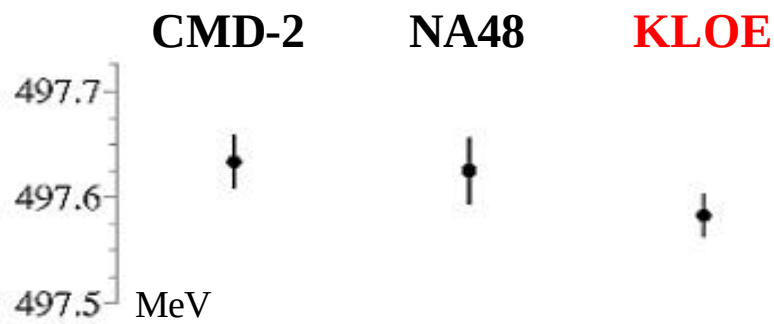


Momentum scale calibrated to CMD-2 '01
$m(\phi) = 1019.483 \pm 0.011 \pm 0.025$ MeV

$$W = M(e^+e^-)$$
$$P = \mathbf{p}(\pi^+) + \mathbf{p}(\pi^-)$$

$$m(K_S) = W^2/4 - P^2$$
$$\delta m/m \approx 0.05(\delta P/P)$$

$m(K_S)$ KLOE preliminary
497.583 ± 0.005 ± 0.020 MeV
KLOE Note 181



Extraction of $\delta_0 - \delta_2$

Conventional extraction of strong phase shifts from K_S, $K^+ \to \pi\pi$ decays:

$$A_{+-} = \sqrt{2/3}\,A_0 e^{i\delta_0} + \sqrt{1/3}\,A_2 e^{i\delta_2}$$

$$A_{00} = -\sqrt{1/3}\,A_0 e^{i\delta_0} + \sqrt{2/3}\,A_2 e^{i\delta_2}$$

$$A_{+0} = \sqrt{3/4}\,A_2 e^{i\delta_2}$$

- Extraction of $K \to \pi\pi$ amplitudes from measured widths must take into account effective cutoff for processes with γ in final state
- **Including isospin-breaking EM effects:**

$$A_I e^{i\delta_I} \to (A_I + dA_I) e^{i\varepsilon_I}$$

$$\varepsilon_I \equiv \delta_I + \gamma_I \qquad \gamma_I = \text{EM phase shift}$$

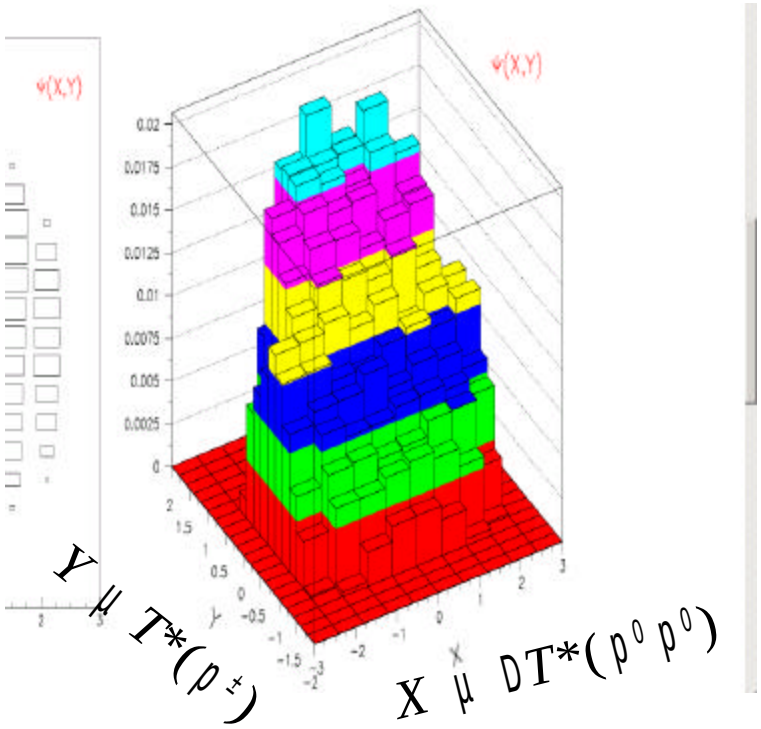
$K \to \pi\pi$ decays actually measure $\varepsilon_0 - \varepsilon_2$

For $\delta_0 - \delta_2$, need theoretical input ($\gamma_0 - \gamma_2$)

$\varepsilon_0 - \varepsilon_2$		$\delta_0 - \delta_2$	
PDG widths Cirigliano et al. '01	**(56 ± 8)°**	**(45 ± 6)°**	χPT estimate Gasser & Meissner, '91
KLOE '02 value for $\Gamma(\pi^+\pi^-)/\Gamma(\pi^0\pi^0)$	**(48 ± 3)°**	**(47.7 ± 1.5)°**	$\pi\pi$ scattering Colangelo et al. '01

$K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$

- Asymmetries in $K^{\pm}$ rates (~10^{-8}) and Dalitz slopes (~10^{-5}) signal direct *CP* viol.
- Dalitz slopes give information on ΔI = 1/2, 3/2 amplitudes for $K \to 3\pi$ decays



Preliminary fit to Dalitz plot

$$F(X,Y) = 1 + gY + hY^2 + kX^2$$

BR($K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$)

PDG '02 fit (1.73 ± 0.04)%

KLOE preliminary hep-ex/0307054

441 pb^{-1} '01+'02 data

187 pb^{-1} counted as signal

(1.781 ± 0.013 ± 0.016)%

	KLOE	PDG
g	**0.586 ± 0.010 ± 0.012**	0.652 ± 0.031
h	**0.030 ± 0.010 ± 0.013**	0.057 ± 0.018
k	**0.0055 ± 0.0026 ± 0.0018**	0.0197 ± 0.0054

$K^{\pm} \to \pi^0 \pi^0 e^{\pm} \nu$ (K_{e4}¢)

Assuming $\Delta I = ½$:

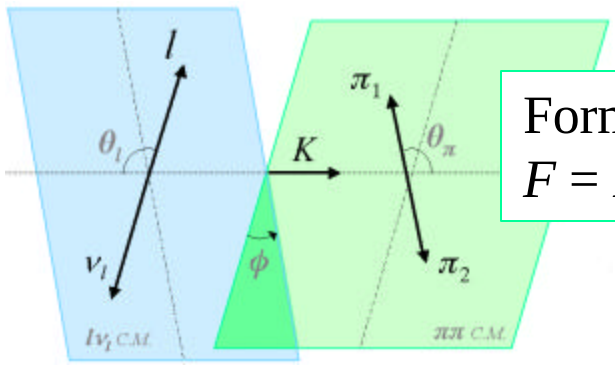
$\Gamma(K_{\ell 4}^{\pm}) = 2\,\Gamma(K_{\ell 4}¢) = ½\,\Gamma(K_{\ell 4}^{0})$

$|F(K_{\ell 4}^{\pm})| = |F(K_{\ell 4}¢)|$

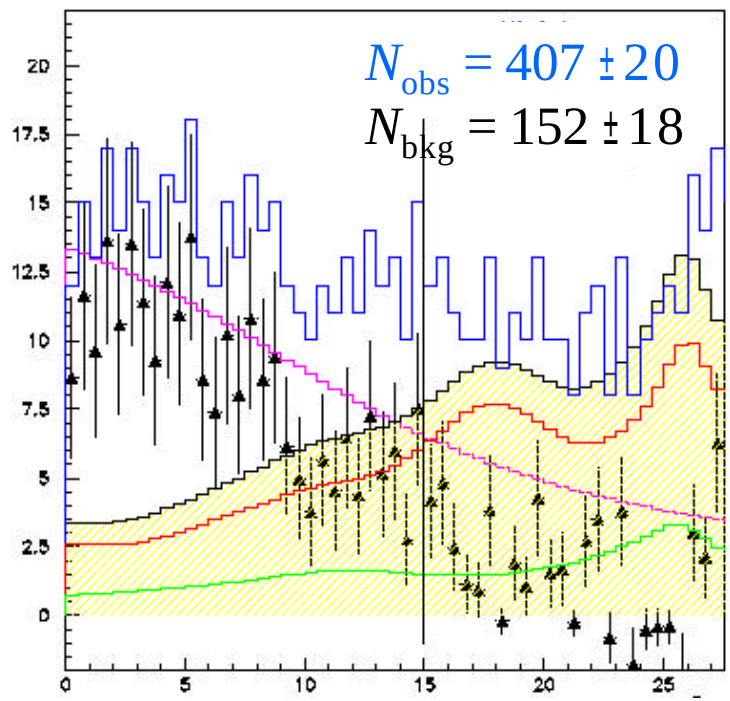
For $K_{\ell 4}¢$, $m_\ell = 0$: $\Gamma = C_F |F|^2 |V_{us}|^2$

$K_{\ell 4}^{\pm}$	$K^{\pm} \to \pi^{+} \pi^{-} \ell^{\pm} \nu$
$K_{\ell 4}¢$	$K^{\pm} \to \pi^{0} \pi^{0} \ell^{\pm} \nu$
$K_{\ell 4}^{0}$	$K_L \to \pi^{0} \pi^{\mp} \ell^{\pm} \nu$

Angular distribution in θ_ℓ, ϕ plane allows determination of $\delta_0^0 - \delta_1^1$



Form factor
$F = F(p_{\pi 1} + p_{\pi 2})$



χ^2 from kinematic fit

KLOE preliminary (441 pb^{-1} '01 + '02 data)

BR(K_{e4}¢)= (2.43 ± 0.20 ± 0.22) × 10^{-5}

PDG fit: (2.1 ± 0.4) × 10^{-5}

Best measurement: (2.54 ± 0.89) × 10^{-5}

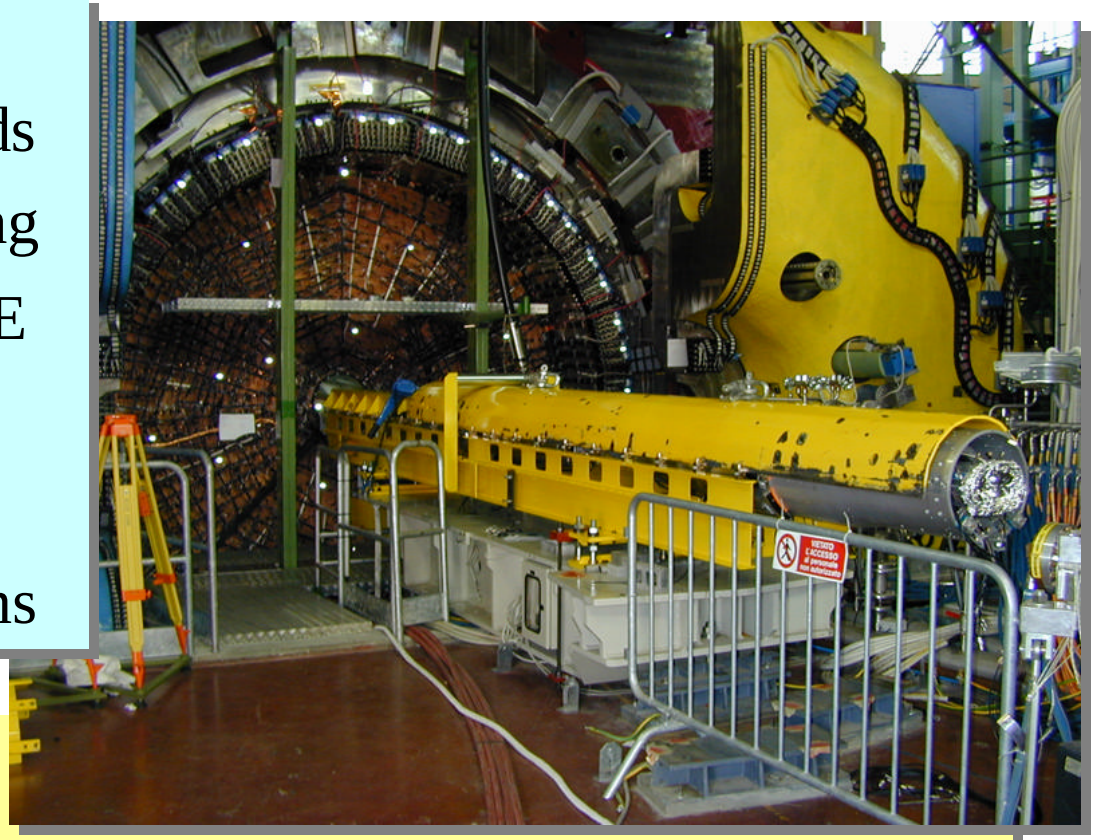
DAΦNE upgrades and 2004 running

New KLOE IR

- Rotation for low-β quads
- Decrease β_x and coupling
- Allow changes to KLOE field

Pole-shims on wigglers

- Eliminate octopole terms



Run plans

- Run started 27 April
- Increase peak luminosity and reach **1.5×10^{32} cm^{-2}s^{-1}**
- Run **KLOE** for **~1 year** with goal of collecting **2 fb^{-1}**

Kaon physics at KLOE

$K_S \to \pi^0\pi^0\pi^0$	Preliminary results, this talk
$K_S \to \pi^+\pi^-(\gamma)$ $K_S \to \pi^0\pi^0$	*Phys. Lett.* **B538** 21 (2002) Update with ’01-’02 data in progress
$K_S \to \pi e \nu$	*Phys. Lett.* **B535** 37 (2002) Preliminary update with ’01-’02 data, this talk
K^0 mass	KLOE Note 181 (http://www.lnf.infn.it/kloe)
$K_L \to \gamma\gamma / K_L \to 3\pi^0$	Phys. Lett. **B566** 61 (2003)
$K_L \to \pi e \nu$ $K_L \to \pi \mu \nu$ $K_L \to \pi^+\pi^-\pi^0$	In progress
V_{us}	In progress
CP violation & interference	In progress
$K^+ \to \pi^+\pi^0\pi^0$	Preliminary results (hep-ex/0307054)

Hadronic physics at KLOE

ϕ meson parameters	Preliminary results
$\phi \to \pi^+\pi^-\pi^0$	*Phys. Lett.* **B561** 55 (2003)
$\eta \to \pi^+\pi^-\pi^0$	Preliminary results
$\eta \to 3\gamma$	hep-ex/0402011, submitted to *Phys. Lett.*
$\phi \to \eta\gamma$	*Phys. Lett.* **B541** 45 (2002) Update with '01-'02 data in progress
$\phi \to f_0\gamma, a_0\gamma$	*Phys. Lett.* **B536** 209 (2002), **B537** 21 (2002) Update with '01-'02 data in progress
$\sigma(e^+e^- \to \text{hadrons})$	Preliminary results (hep-ex/0307051)

Status: s(e^+e^- ® hadrons) and a_m

141 pb^{-1} KLOE '01 DATA – PRELIMINARY

Evaluation of the dispersion integral for the contribution to a_m from e^+e^- ® p p in the energy range $0.35 < m^2_{pp} < 0.95$ GeV^2:

$$a_m^{pp} = (389.2 \pm 0.8_{stat} \pm 4.7_{syst} \pm 3.7_{th}) \times 10^{-10}$$

Comparison with CMD-2 in the energy range $0.37 < m^2_{pp} < 0.93$ GeV^2:

KLOE*	$(376.5 \pm 0.8_{stat} \pm 5.4_{syst+th}) \times 10^{-10}$
CMD-2	$(378.6 \pm 2.7_{stat} \pm 2.3_{syst+th}) \times 10^{-10}$

* Error on model dependence FSR and VP not included!

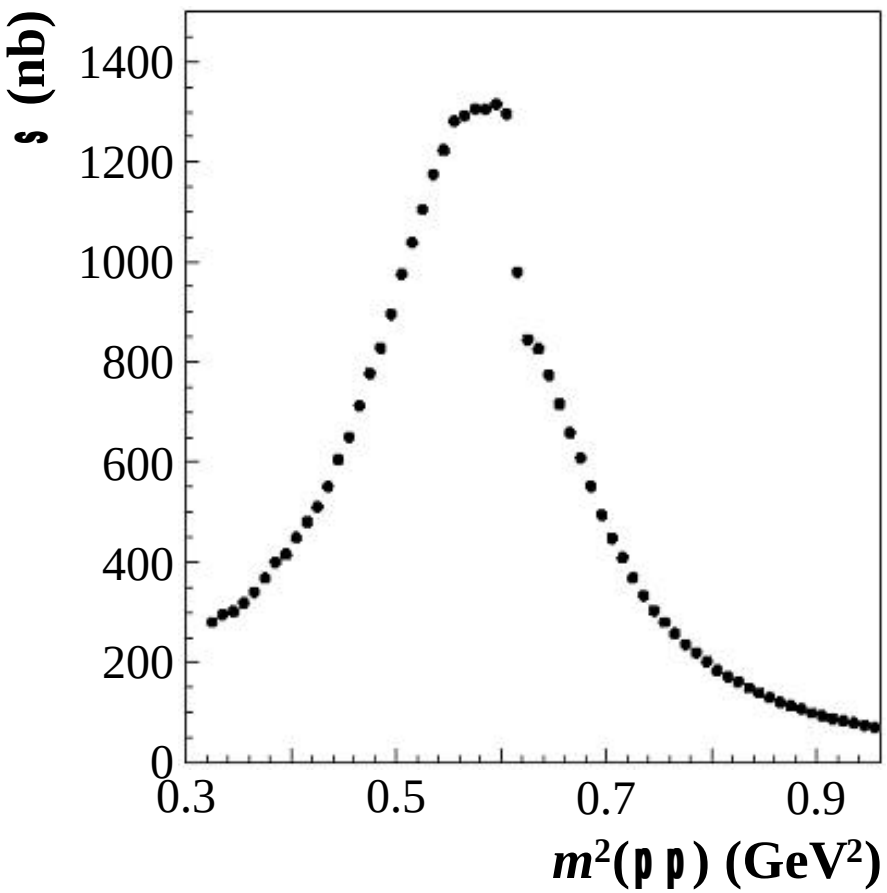
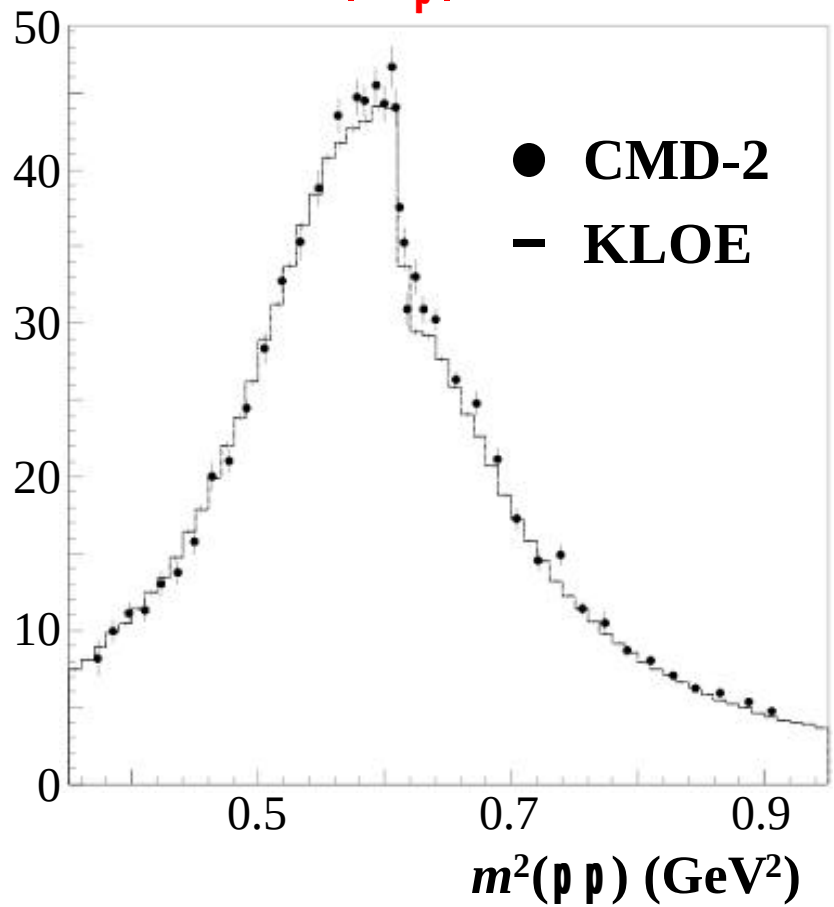
KLOE results **confirm** ~10% discrepancy between e^+e^- data and t data for $m^2_{pp} > 0.6$ GeV^2

Publication ready for final collaboration review

Status: $s(e^+e^- \to hadrons)$ *and* $|F_p|^2$

141 pb^{-1} KLOE '01 DATA – PRELIMINARY

$s(e^+e^- \to p^+p^-)$



$|F_p|^2$