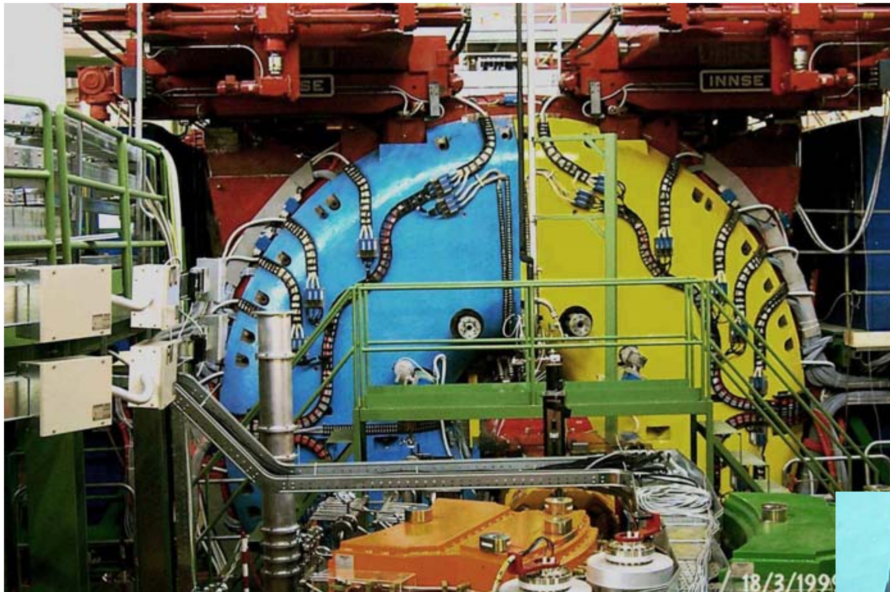
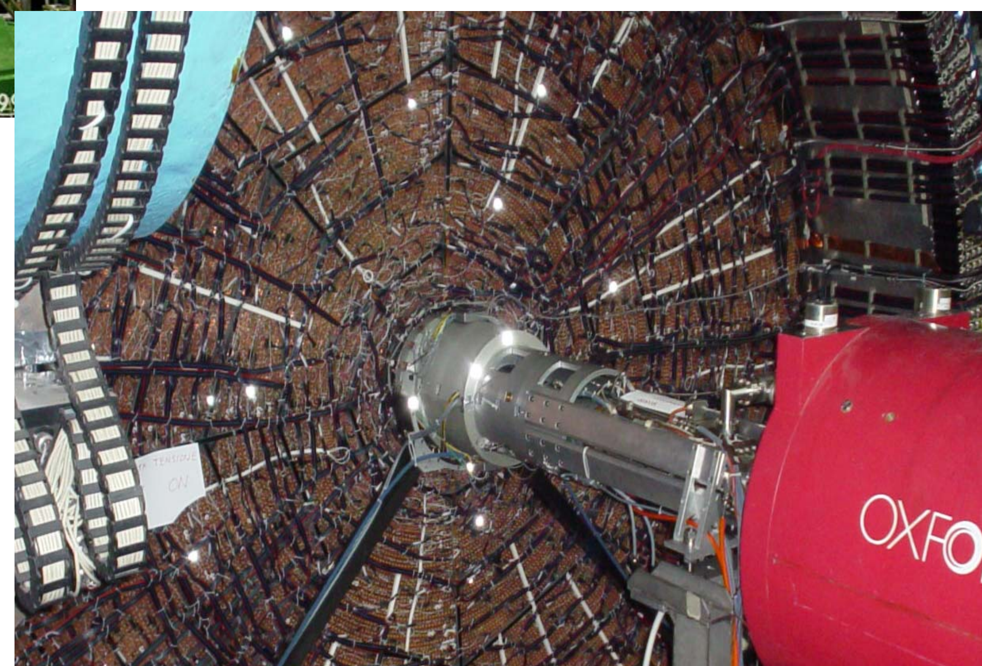
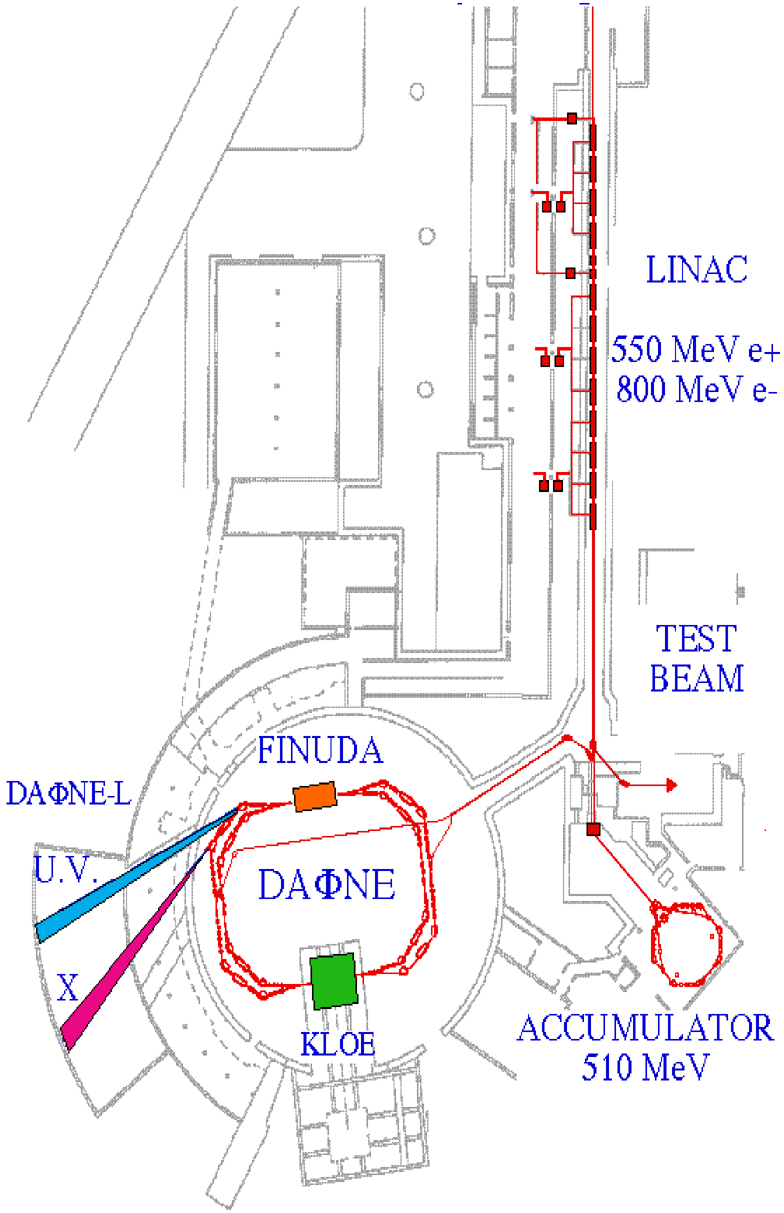
Recent results from **KLOE**

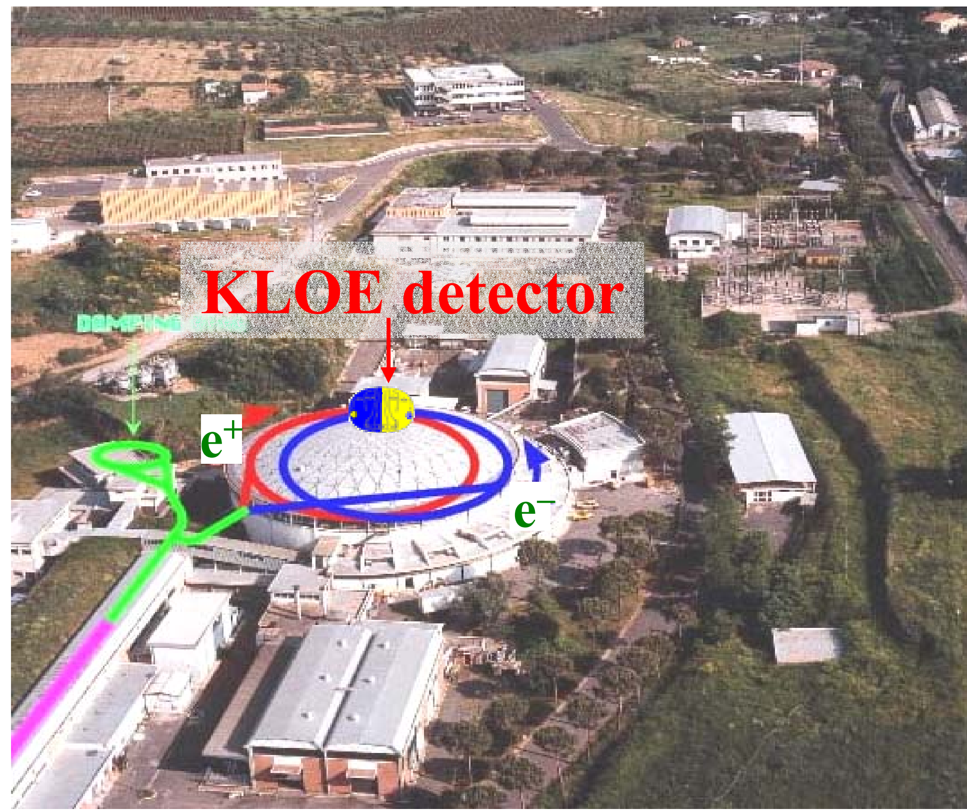


Fabio Bossi, LNF-INFN



The *DAΦNE* complex

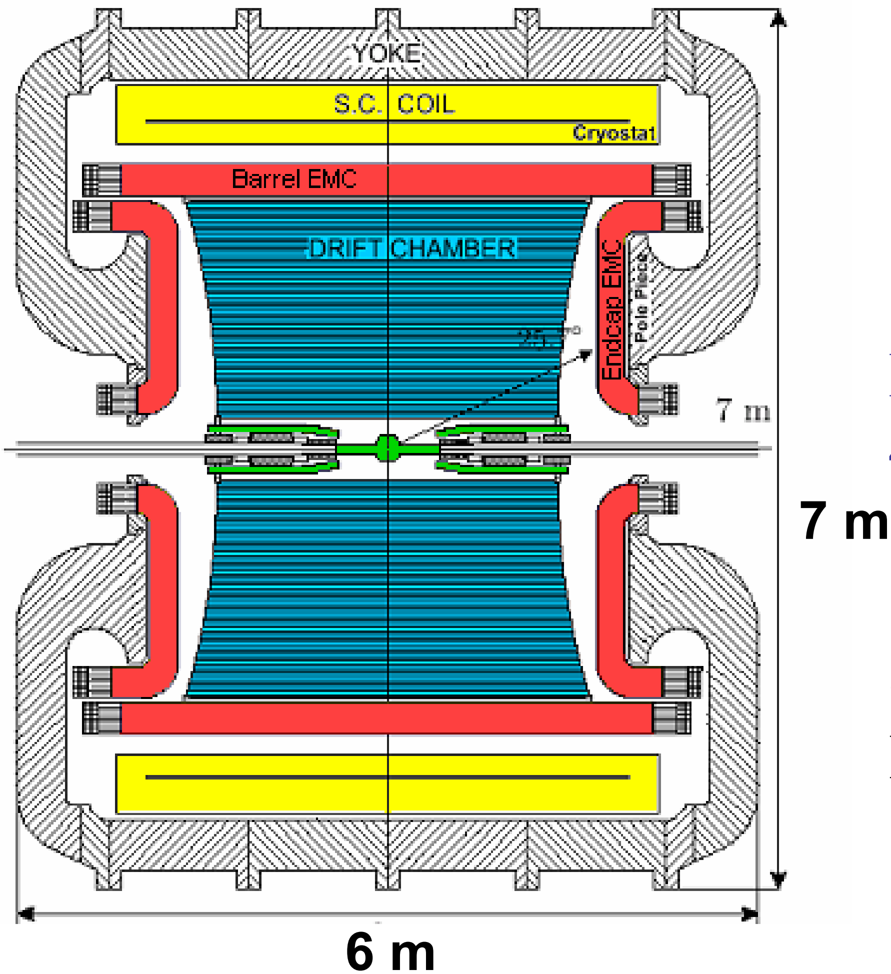




DAΦNE parameters	Design	2002	Goals 2003-04
Max. bunches	120	51	110
Lifetime (mins)	120	40	70
Bunch current (mA)	40	20	20
$\mathcal{L}$, single bunch ($cm^{-2}s^{-1}$)	$4.4 \cdot 10^{30}$	$1.5 \cdot 10^{30}$	$2 \cdot 10^{30}$
$\mathcal{L}$, peak ($cm^{-2}s^{-1}$)	$5.3 \cdot 10^{32}$	$0.75 \cdot 10^{32}$	$2 \cdot 10^{32}$

- W = Mϕ = 1019 MeV
- Separate e^+, e^- rings minimize beam-beam interactions
- Beams cross at 12.5 mrad angle
- Injection during data-taking

The *KLOE* detector



❖ **Superconducting coil** $B = 0.52$ T

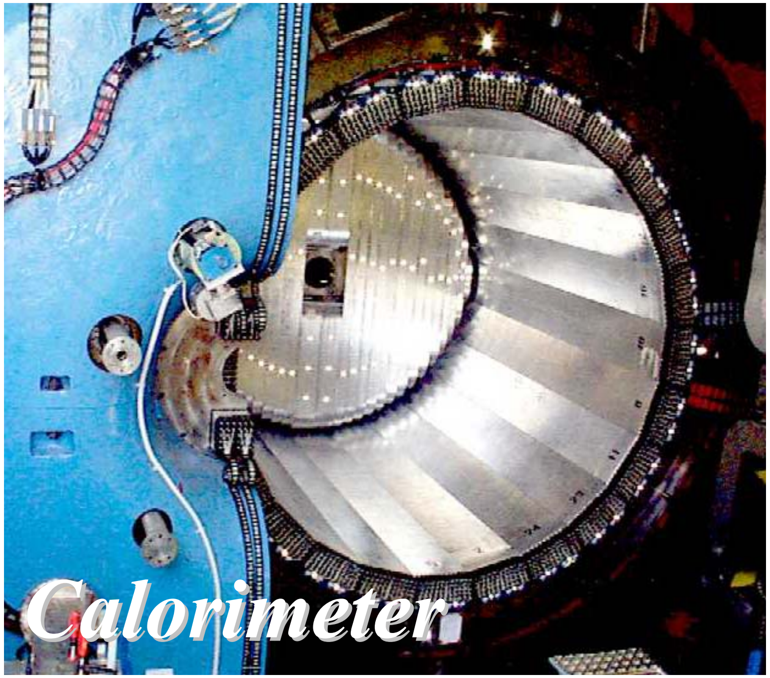
❖**Be beam pipe** (0.5 mm thick)

❖**Electromagnetic calorimeter**
Lead/scintillating fibers (1 mm ∅)
4880 PMT's, 15 X_0

❖**Drift chamber**
(4 m ∅ × 3.3 m) 90% He + 10% IsoB, CF frame, 12582 stereo, single sense wire, "almost squared" cells

❖**Quadrupole calorimeter**

Detector performance



σ_E/E 5.7% $/\sqrt{E(\mathrm{GeV})}$

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

σ^{vertex} ~ 1.5 cm

σ_p/p 0.4 % (tracks with $\vartheta > 45°$)

σ_{xy}^{hit} 150 μm, σ_z^{hit} 2 mm

σ^{vertex} ~ 3 mm

$\sigma_M(K_S)$ ~1 MeV

Kaons @ *KLOE*

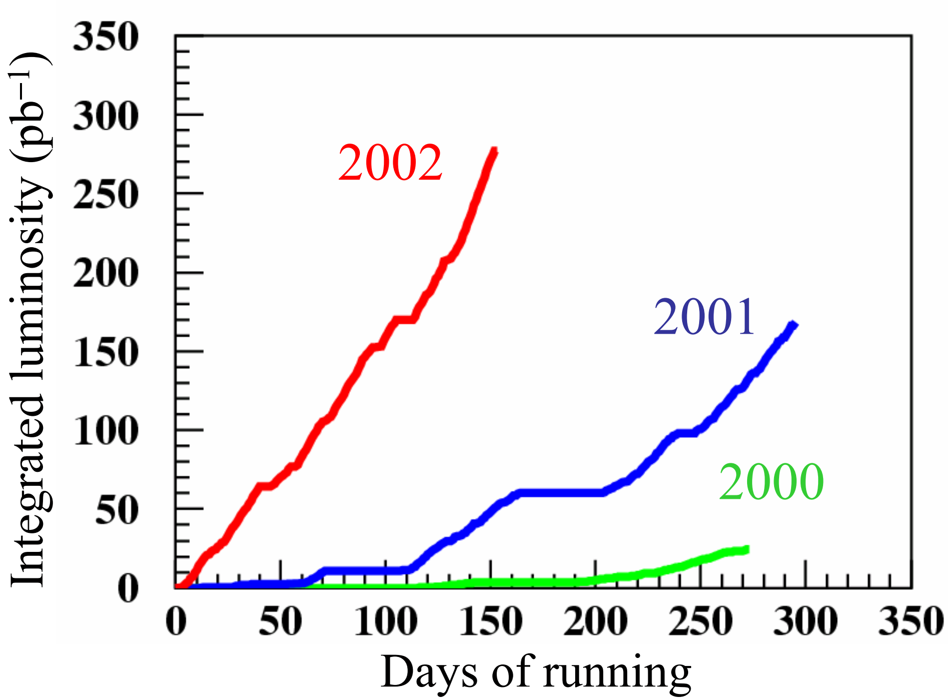
The Φ decay at rest provides *monochromatic* and *pure* beams of Kaons

- *K* rare decays
- *Absolute* branching ratios
- *K* lifetimes

K^+K^-	1.5×10^6 /pb^{-1}	p* = 127 MeV/c
K_LK_S	10^6 /pb^{-1}	p* = 110 MeV/c

The variety of *K* decay channels and the possibility for a complete closure of the kinematics allow the selection of many samples for *measuring the efficiencies directly from data.*

KLOE Data taking: 2000-2002



2000: 25 pb^{-1} **80·10^6 Φ decays**	*First published results*
2001: 176 pb^{-1} **550·10^6 Φ decays** **2002: 296 pb^{-1}** **920·10^6 Φ decays**	*Analysis in progress*

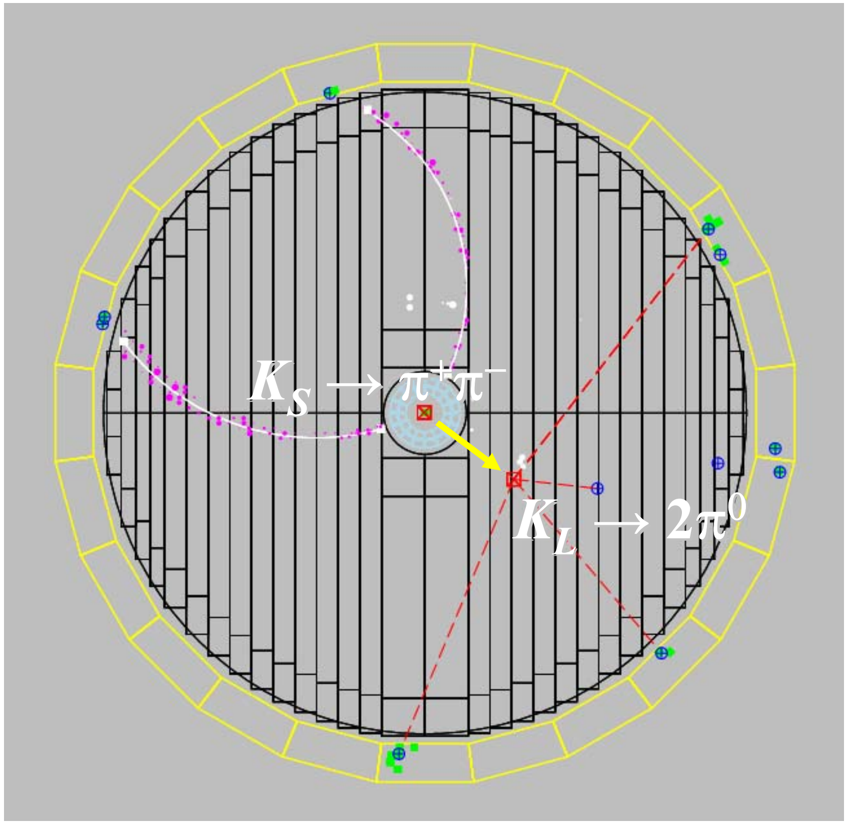
Particles' collection:

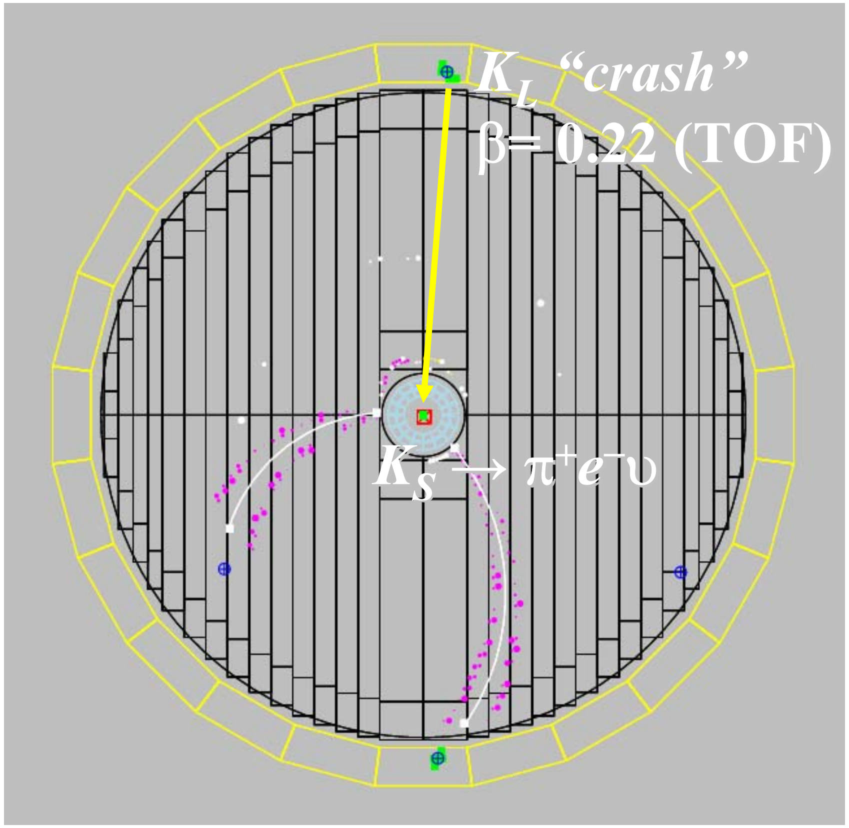
- $7\cdot10^8$ $K^+ K^-$ pairs
- $5\cdot10^8$ $K_S K_L$ pairs
- $2\cdot10^7$ η

Kaon physics @ *KLOE*

$K_S \rightarrow \pi^+\pi^-(\gamma)$ $K_S \rightarrow \pi^0\pi^0$	*Phys. Lett.* **B538** 21 (2002)
$K_S \rightarrow \pi e \nu$	*Phys. Lett.* **B537** 21 (2002) Preliminary update with 2001 data
K_S mass	KLOE Note 181 (http://www.lnf.infn.it/kloe)
$K_L \rightarrow \gamma\gamma / K_L \rightarrow 3\pi^0$	*Phys. Lett.* **B566** 61 (2003)
$K_L \rightarrow$ charged	Preliminary results
CP violation & interference	Preliminary results
$K^\pm \rightarrow \pi^\pm\pi^0\pi^0$	hep-ex/0307054, submitted to EPS'03, LP'03
$K^\pm \rightarrow \pi^0\pi^0 e^\pm \nu$	Preliminary results
V_{us}	Preliminary results

Tagged K_L and K_S "beams"





K_L tagged by $K_S \to \pi^+\pi^-$ at IP
Efficiency ~ 70% (mainly geometrical)
K_L angular resolution: ~ 1°
K_L momentum resolution: ~ 2 MeV

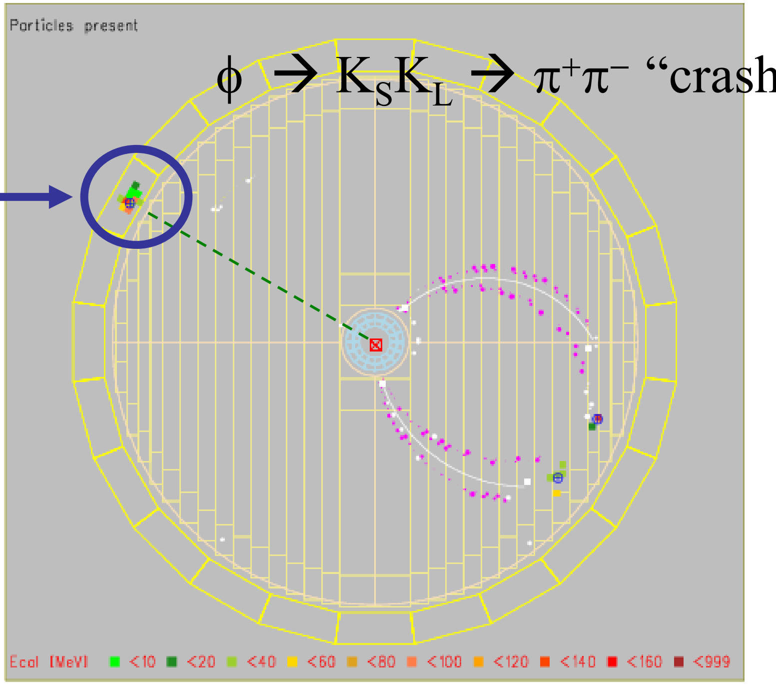
K_S tagged by K_L interac. in EmC
Efficiency ~ 30% (largely geometrical)
K_S angular resol.: ~ 1° (0.3° in Φ)
K_S momentum resolution: ~ 2 MeV

K_S tagging

- Clean $\mathbf{K_S}$ tagging by time-of-flight identification of $\mathbf{K_L}$ interactions in the calorimeter
- K_L velocity in the ϕ rest frame

  $\beta^* \sim 0.218$

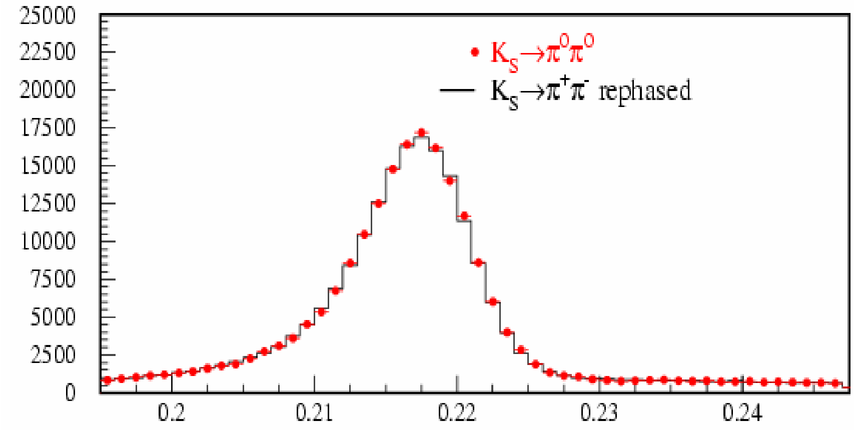
- Tagging efficiency $\varepsilon_{tag,total} \sim 30\%$



KLOE has now about **1.5 10⁸ tagged K_S.**
Almost all channels are accessible.
Results from 2000 data (**5.4 10^6 tagged K_S**) on:

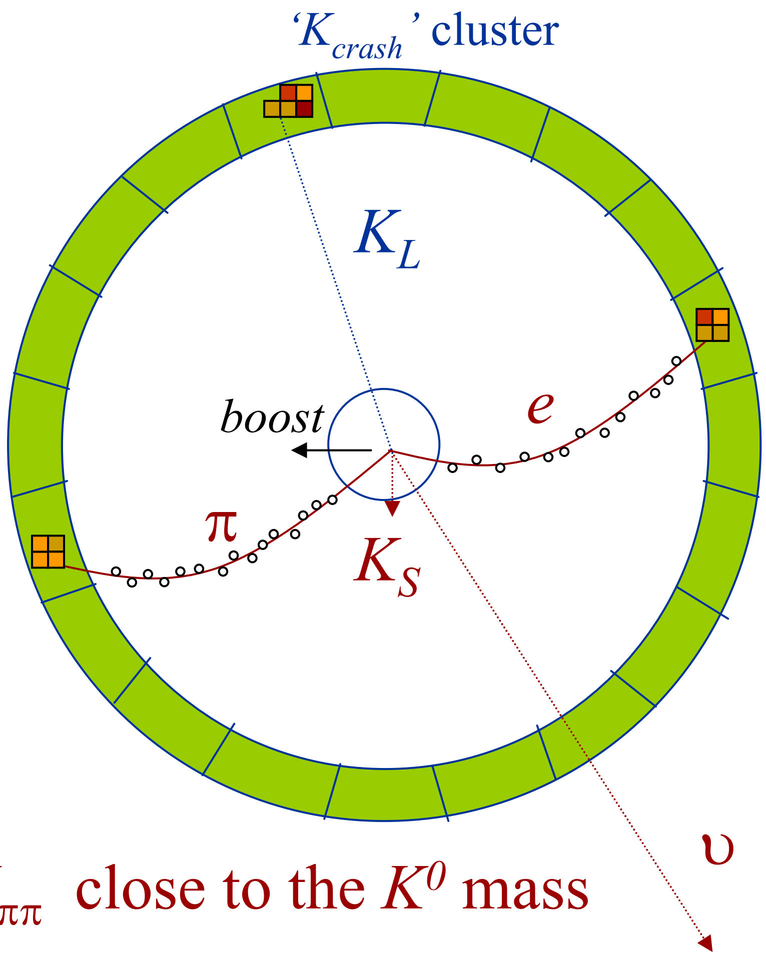
(1) $R=\Gamma(K_S \rightarrow \pi^+\pi^-) / \Gamma(K_S \rightarrow \pi^0\pi^0)$
(2) $BR(K_S \rightarrow \pi^\pm e^\pm \nu)$

Phys. Lett. **B 538** (2002), 21
Phys. Lett. **B 535** (2002), 37



β^* distribution of "K_L crash"

BR($K_S \to \pi e \nu$)



Events tagged by a 'K_{crash}' cluster

2 tracks and 1 vertex close to the IP

Reject events with invariant mass $M_{\pi\pi}$ close to the K^0 mass

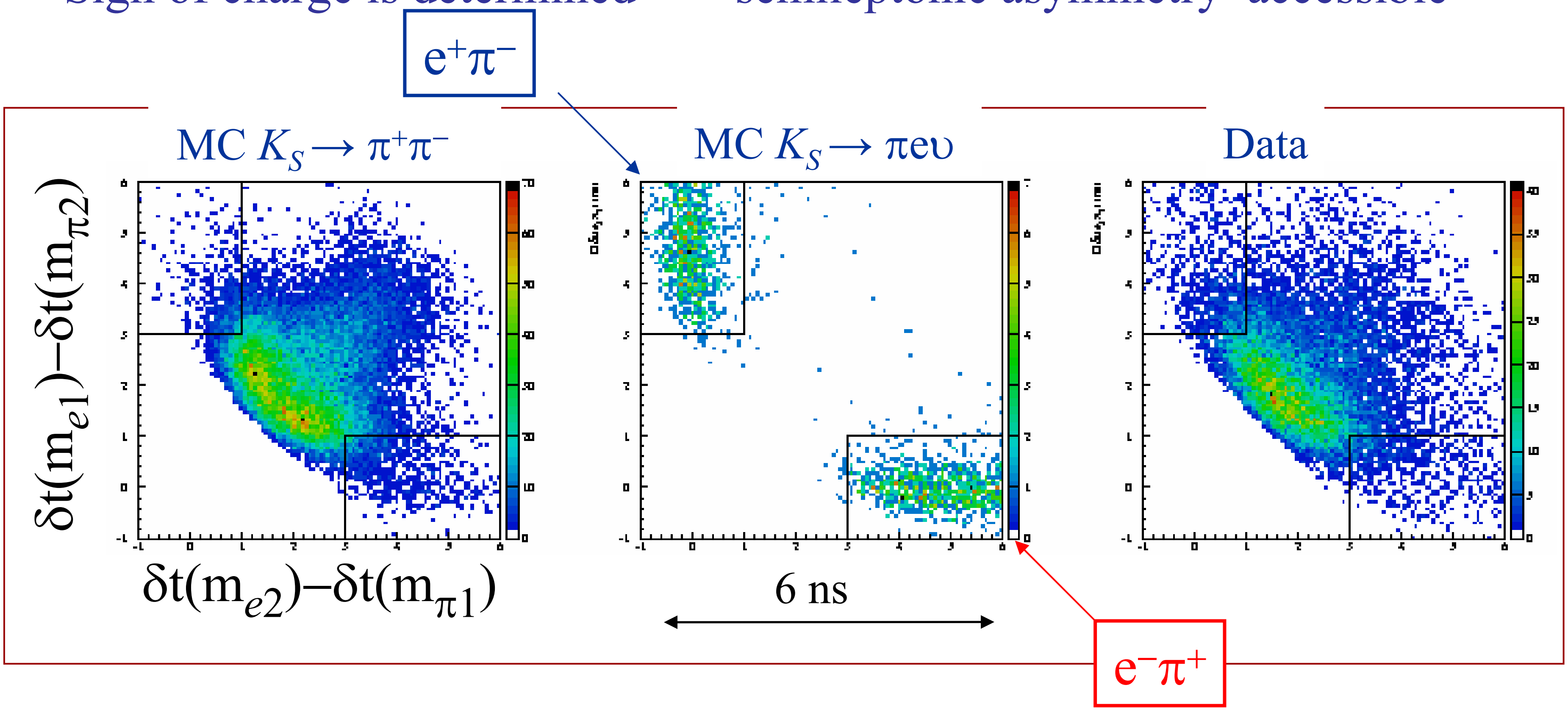
Use time information from calorimeter clusters to perform PID for charged tracks

π/e identification

- Time of flight *e/π* identification ($\delta t < 2$ ns) :

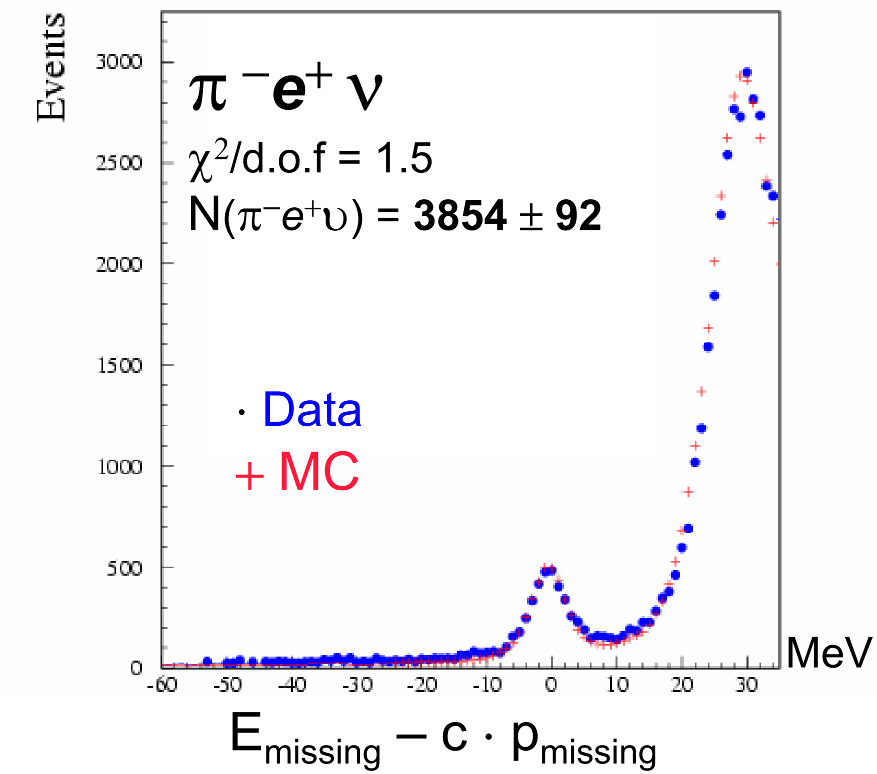
$$\delta t(m) = t_{cluster} - t.o.f. \text{ calculated with mass hypothesis } m$$

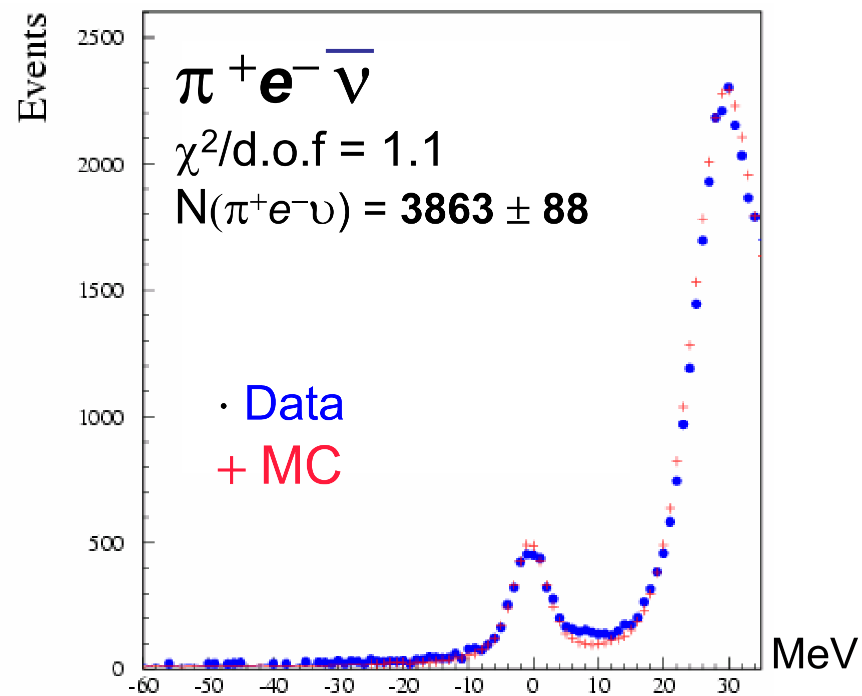
- Sign of charge is determined → semileptonic asymmetry accessible



BR($K_S \to \pi e \nu$)

KLOE '03 preliminary result **170 pb^{-1}** 2001 data

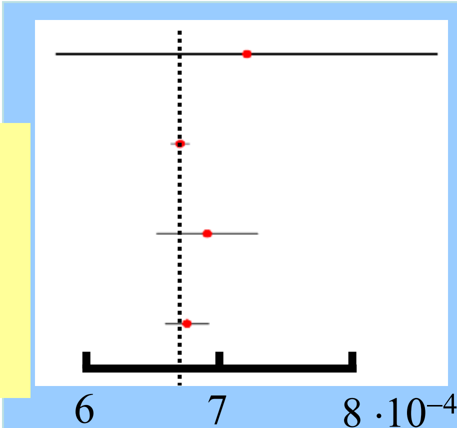




BR($\pi^- e^+ \upsilon$) = (3.46 ± 0.09 ± 0.06) · 10^{-4}

BR($\pi^+ e^- \upsilon$) = (3.33 ± 0.08 ± 0.05) · 10^{-4}

BR($\pi^\mp e^\pm \upsilon$) = (6.81 ± 0.12 ± 0.10) · 10^{-4}



BR($K_S \to \pi e \nu$): charge asymmetry

$$\langle \pi^+ e^- \upsilon | H_W | K^0 \rangle = a + b$$
$$\langle \pi^- e^+ \upsilon | H_W | \bar{K}^0 \rangle = a^* - b^*$$

$$\langle \pi^- e^+ \upsilon | H_W | K^0 \rangle = c + d$$
$$\langle \pi^+ e^- \upsilon | H_W | \bar{K}^0 \rangle = c^* - d^*$$

In the ***SM***:
b=d=0 if ***CPT*** holds

Suppressed by ***ΔS=ΔQ*** rule
(c=d=0)

$$A = \frac{N^+ - N^-}{N^+ + N^-}$$

$$A_S = 2(\mathrm{Re}\,\varepsilon_K + \mathrm{Re}\,\delta_K + \mathrm{Re}\,b/a - \mathrm{Re}\,d^*/a)$$
$$A_L = 2(\mathrm{Re}\,\varepsilon_K - \mathrm{Re}\,\delta_K + \mathrm{Re}\,b/a + \mathrm{Re}\,d^*/a)$$

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

~~CP~~	~~CPT~~ in mixing	~~CPT~~ in decay	ΔS=ΔQ and ~~CPT~~

preliminary

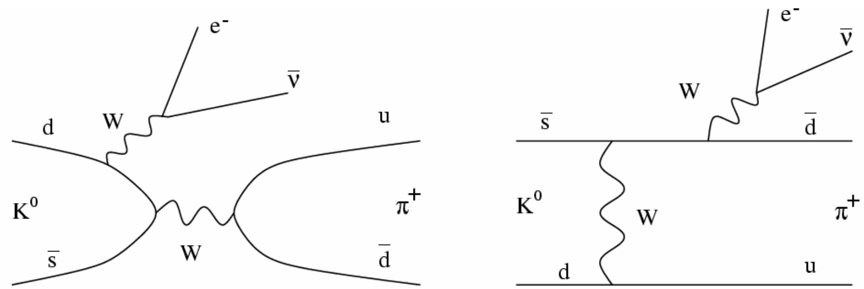
***KLOE*: first measurement of A_S!**

$$A_S = (19 \pm 17_{stat} \pm 6_{syst}) \times 10^{-3}$$

***KTeV* 2002 for $A_L = (3.322 \pm 0.058_{stat} \pm 0.047_{syst}) \times 10^{-3}$**

BR($K_S \to \pi e \nu$): $\Delta S = \Delta Q$ rule

No $\Delta S \neq \Delta Q$ transitions at tree level
($\Delta S \neq \Delta Q$ in higher order transitions)



$$\mathrm{Re}\, x_+ = \frac{1}{2}\,\frac{\mathrm{BR}_S(\pi e \upsilon)/\tau_S - \mathrm{BR}_L(\pi e \upsilon)/\tau_L}{\mathrm{BR}_S(\pi e \upsilon)/\tau_S + \mathrm{BR}_L(\pi e \upsilon)/\tau_L}$$

preliminary

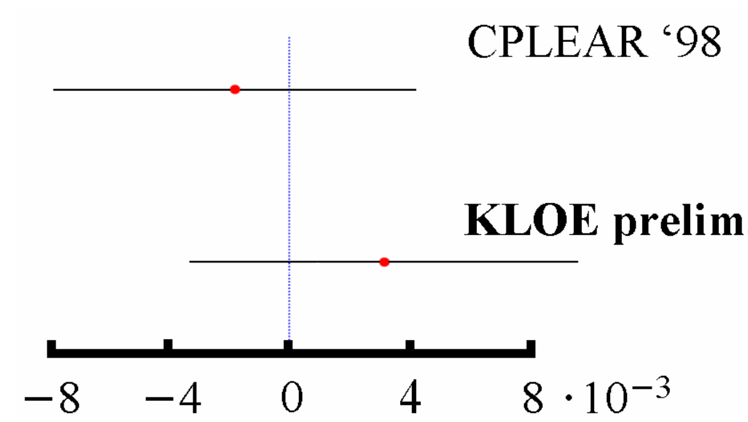
$\Delta S = \Delta Q$ Test (SM: $\lvert x_+\rvert \sim 10^{-7}$)
$\mathrm{Re}\, x_+ = (2.2 \pm 5.3_{stat} \pm 3.5_{syst}) \times 10^{-3}$

CPLEAR '98: $\mathrm{Re}\, x_+ = (-1.8 \pm 4.1_{stat} \pm 4.5_{syst}) \times 10^{-3}$

$x = (c^* - d^*)/(a + b)$
$\Delta S \neq \Delta Q$ in $\overline{K}^0$ decay to e^+

$\overline{x} = (c + d)/(a^* - b^*)$
$\Delta S \neq \Delta Q$ in K^0 decay to e^-

$\boldsymbol{x_+ = (x + \overline{x})/2 \approx c^*/a}$
$\Delta S \neq \Delta Q$ if *CPT* conserved

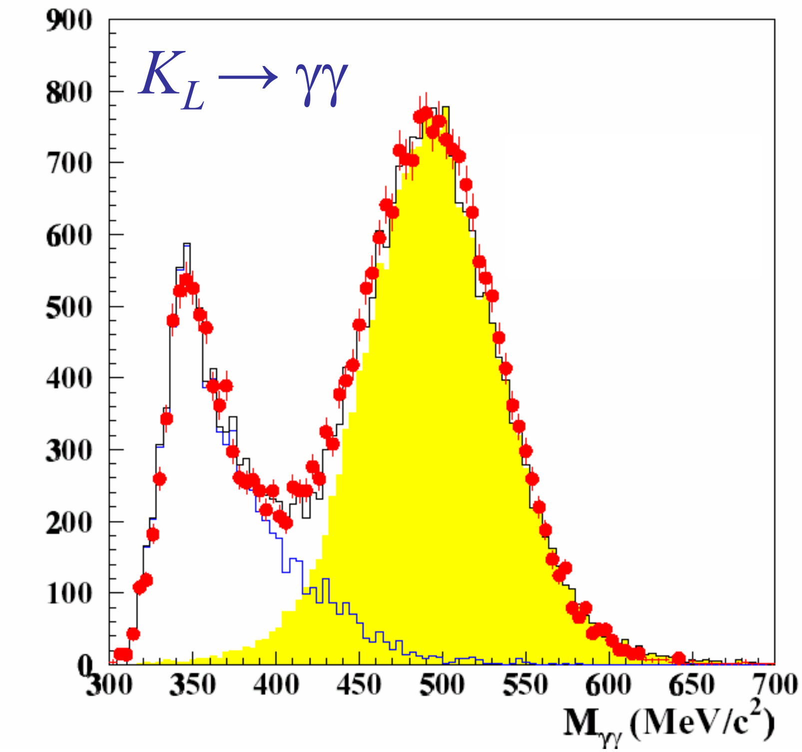


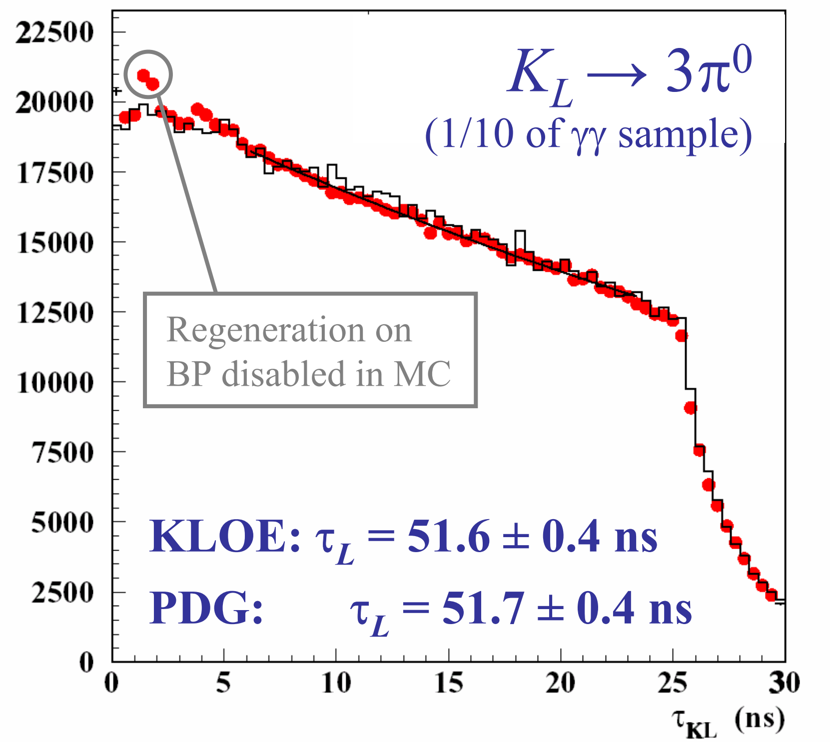
280 pb^{-1} from '02 running +
KLOE measurements of τ_L,
BR($K_L \to \pi e \upsilon$) on the way

$\Gamma(K_L \to \gamma\gamma)/\Gamma(K_L \to \pi^0\pi^0\pi^0)$

- Dominated by long-distance contribution $K_L \to \gamma\gamma$
- Dominates long-distance contribution to $K_L \to \mu^+\mu^-$

Exploits performance of EmC for reconstruction of photon vertex





***KLOE* '03: $(2.793\pm0.022\pm0.024)\cdot10^{-3}$**

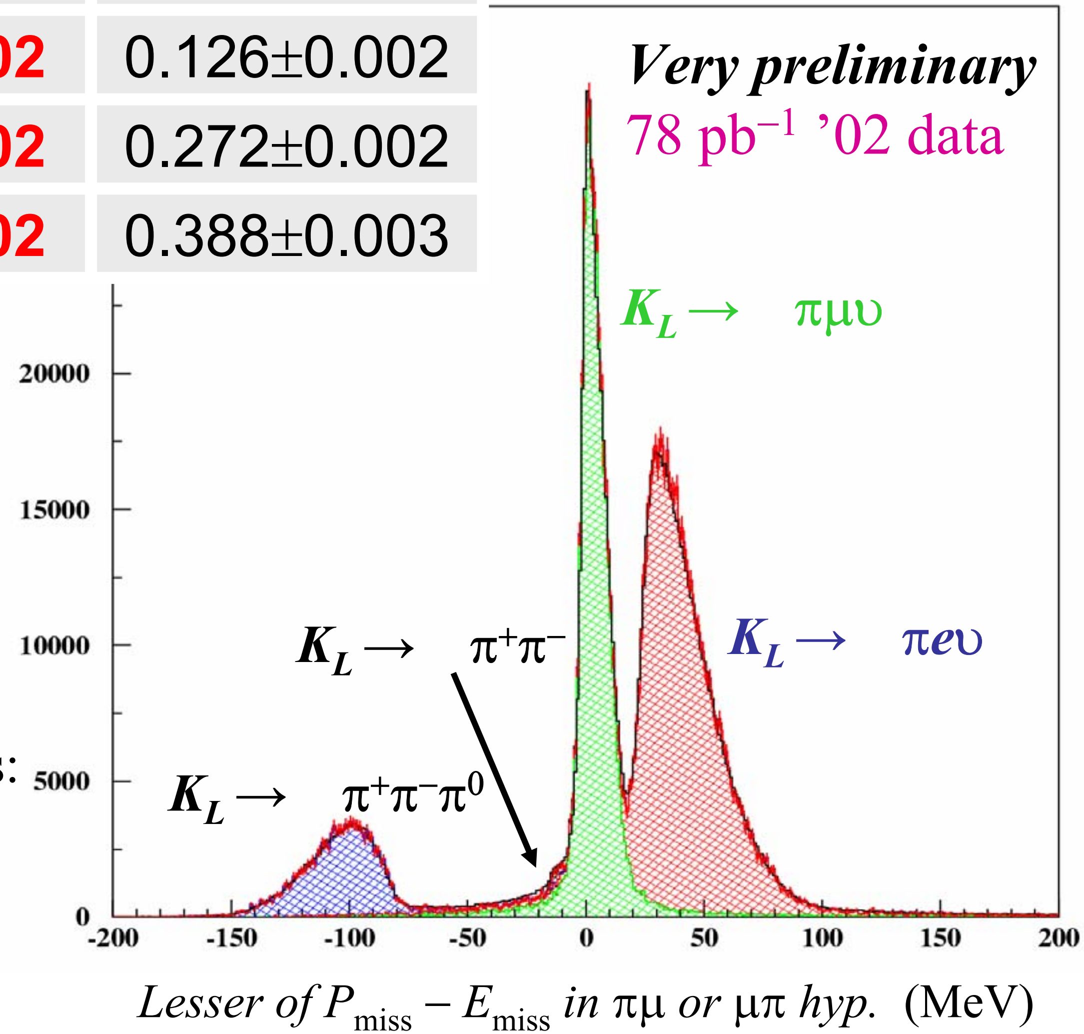
362 pb^{-1} '01+'02 data, *Phys. Lett.* **B566** 61

NA48 '02: $(2.81\pm0.01\pm0.02)\cdot10^{-3}$

PDG '02: $(2.82\pm0.08)\cdot10^{-3}$

$K_L \rightarrow$ charged particles

BR	***KLOE***	PDG '02
$K_L \rightarrow \pi^+\pi^-\pi^0$	**0.132±0.002**	0.126±0.002
$K_L \rightarrow \pi\mu\nu$	**0.271±0.002**	0.272±0.002
$K_L \rightarrow \pi e\nu$	**0.384±0.002**	0.388±0.003



Errors are statistical only!
(including MC statistics)

Systematic errors also ~1-2%
but not yet fully evaluated

$K_L \rightarrow \pi^+\pi^-$ contribution fixed

BR($K_L \rightarrow \pi^+\pi^-$), similar analysis:
KLOE $(2.04 \pm 0.04)\cdot 10^{-3}$
PDG '02 $(2.084 \pm 0.032)\cdot 10^{-3}$

Very preliminary!

Kaon interferometry

Double differential *decay time* distribution

$$I(f_1,t_1;f_2,t_2)=C_{12}\left\{|\eta_1|^2 e^{-\Gamma_L t_1-\Gamma_S t_2}+|\eta_2|^2 e^{-\Gamma_S t_1-\Gamma_L t_2}-2|\eta_1||\eta_2|e^{-(\Gamma_S+\Gamma_L)(t_1+t_2)/2}\cos[\Delta m(t_1-t_2)+\phi_2-\phi_1]\right\}$$

$f_i = \pi^+\pi^-,\ \pi^0\pi^0,\ \pi l\nu,\ \pi^+\pi^-\pi^0,\ 3\pi^0,\ \pi^+\pi^-\gamma$ ..etc

Interference terms

Integral *decay time* distribution

$$I(f_1,f_2;\Delta t\geq 0)=\frac{C_{12}}{\Gamma_S+\Gamma_L}\left[|\eta_1|^2 e^{-\Gamma_L\Delta t}+|\eta_2|^2 e^{-\Gamma_S\Delta t}-2|\eta_1||\eta_2|e^{-(\Gamma_S+\Gamma_L)\Delta t/2}\cos(\Delta m\Delta t+\phi_2-\phi_1)\right]$$

for $\Delta t<0 \quad \Delta t\rightarrow|\Delta t|$ and $1\leftrightarrow 2$

From the fit to these, for the arious decay channels one gets

$$\Gamma_S\ ,\ \Gamma_L\ ,\Delta m\ ,\ |\eta_i|\ ,\arg(\eta_i)=\phi_i$$

A first glance at interference

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

***KLOE* preliminary**

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

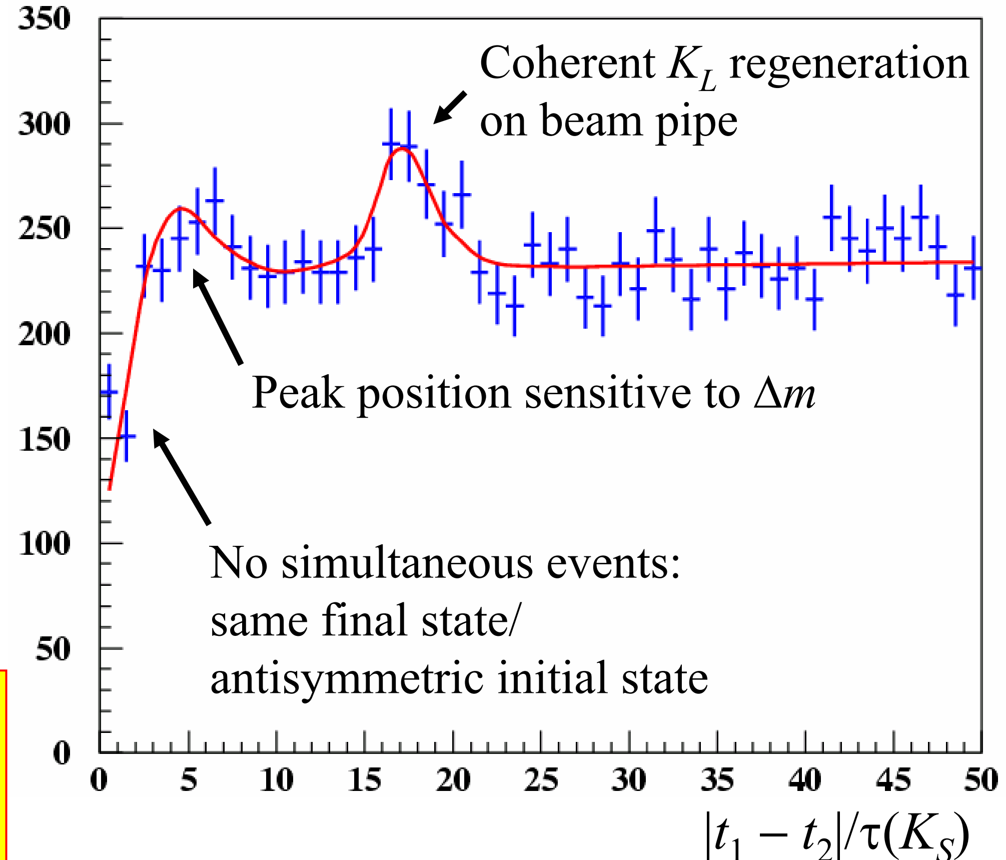
Fit with PDG values for Γ_S, Γ_L

χ^2/d.o.f. = 43.7/47

$\Delta m = (5.64 \pm 0.37)\times10^{-11}\ \hbar\ s^{-1}$

PDG '02: $(5.301 \pm 0.016)\times10^{-11}\ \hbar\ s^{-1}$

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



$\phi \to K_S K_L \to \pi^+\pi^- \; \pi^+\pi^-$: measurement of decoherence

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

interference term modified introducing a *decoherence* parameter ζ:

$\zeta=0$ → "orthodox" QM

$\zeta=1$ → Furry's hypothesis (spontaneous factorization) [W.Furry, P.R.49 (1936) 393]

decoherence ζ depends on which basis the initial state is written (QM ***does not!***)

R.A. Bertlmann et al., Phys. Rev. D60 (1999) 114032 using CPLEAR data obtain:

$$\zeta_{K_S,K_L} = 0.13 \pm 0.16$$

$$\zeta_{K^0,\overline{K}^0} = 0.4 \pm 0.7$$

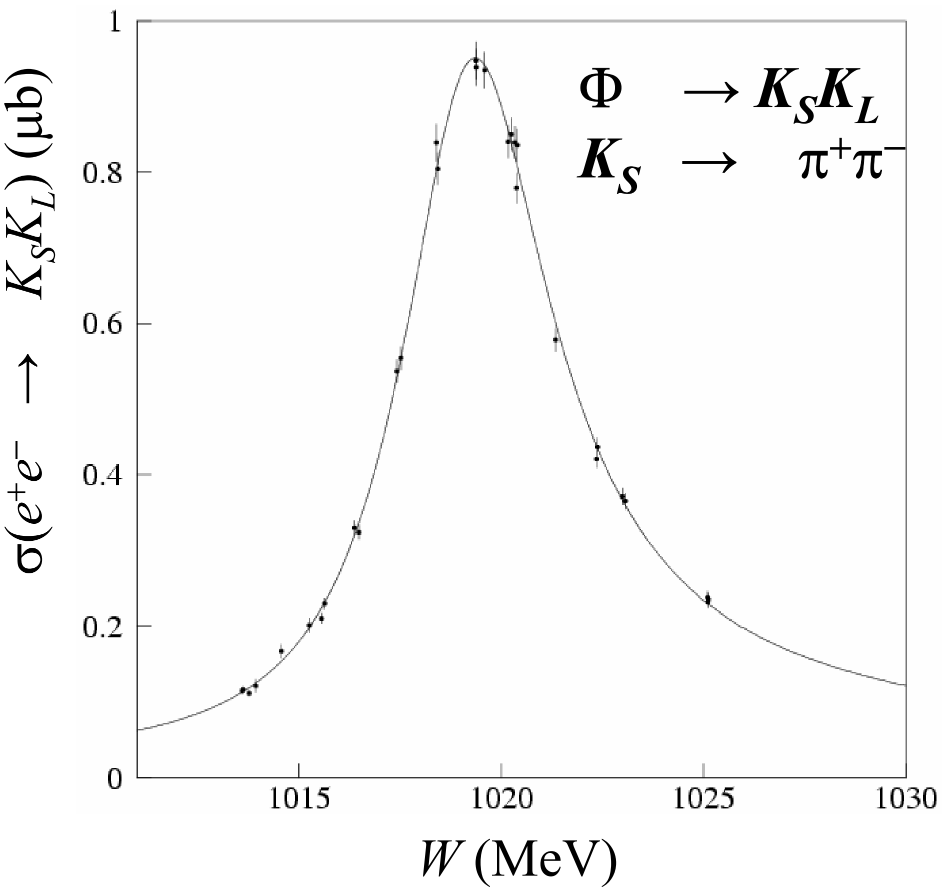
KLOE **VERY PRELIMINARY (340 pb^{-1}):**

$$\zeta_{K_S K_L} = 0.12 \pm 0.08$$

$$\zeta_{K^0\overline{K}^0} = (0.8 \pm 0.5)\times 10^{-5}$$

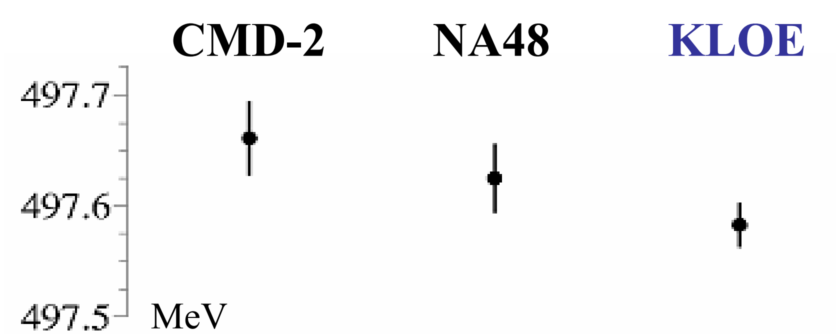
An interlude: K_S mass determination

Φ peak scan (2001): 29 pts, 0.5 pb^{-1}



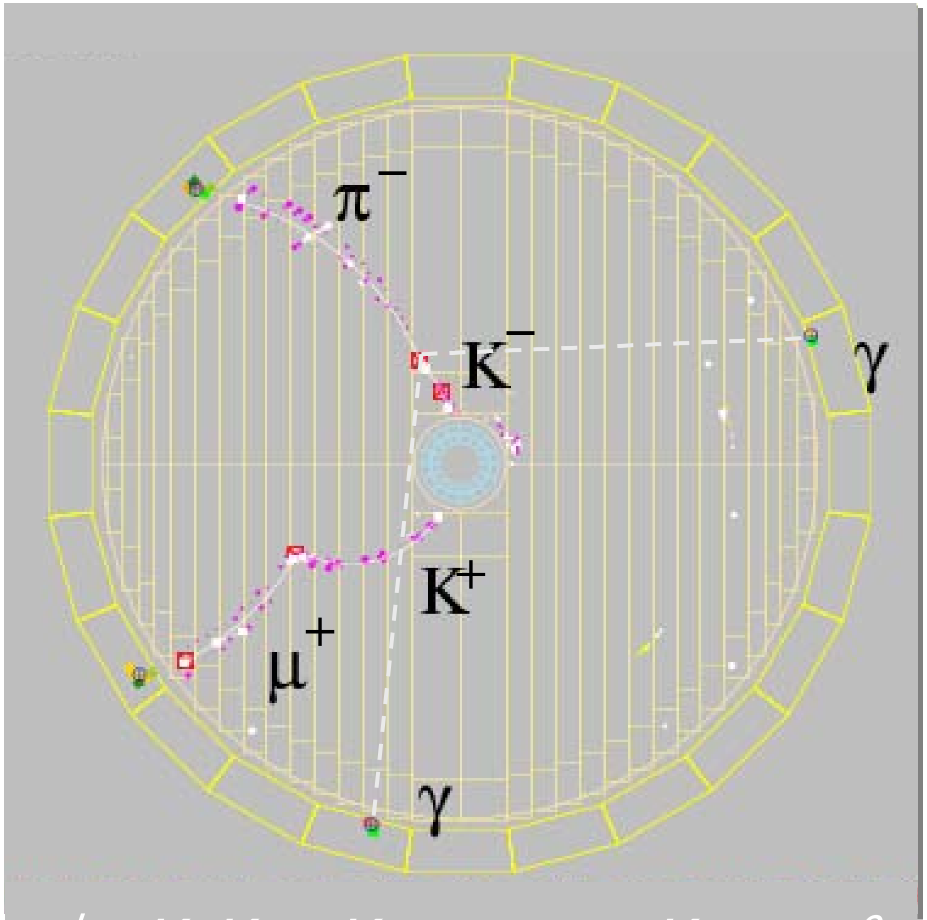
Momentum scale calibrated to CMD-2 ’01
$m(\Phi) = 1019.483 \pm 0.011 \pm 0.025$ MeV

$m(K_S)$ *KLOE* preliminary
$497.583 \pm 0.005 \pm 0.020$ MeV
KLOE Note 181



Charged kaons @ *KLOE*

- BR ($\phi \to K^+K^-$) = 49.4 %
- Decay length K^+K^- = 95 cm
- $P_K \approx$ 100 MeV/c ($\beta_K \approx 0.2$)
- dE/dx at beam pipe and DC wall up to 30 MeV/c (20 %)
- 40% of the $K^\pm$ decays outside the tracking volume

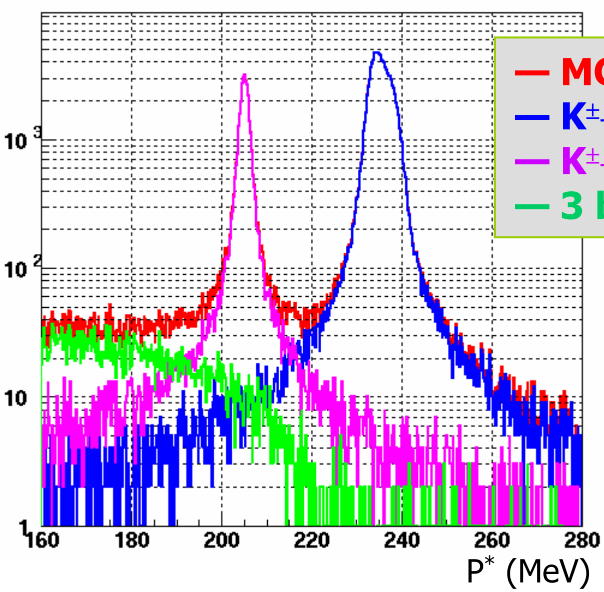


$\phi \to K^+K^-$; $K^+ \to \mu^+\nu_\mu$, $K^- \to \pi^-\pi^0$

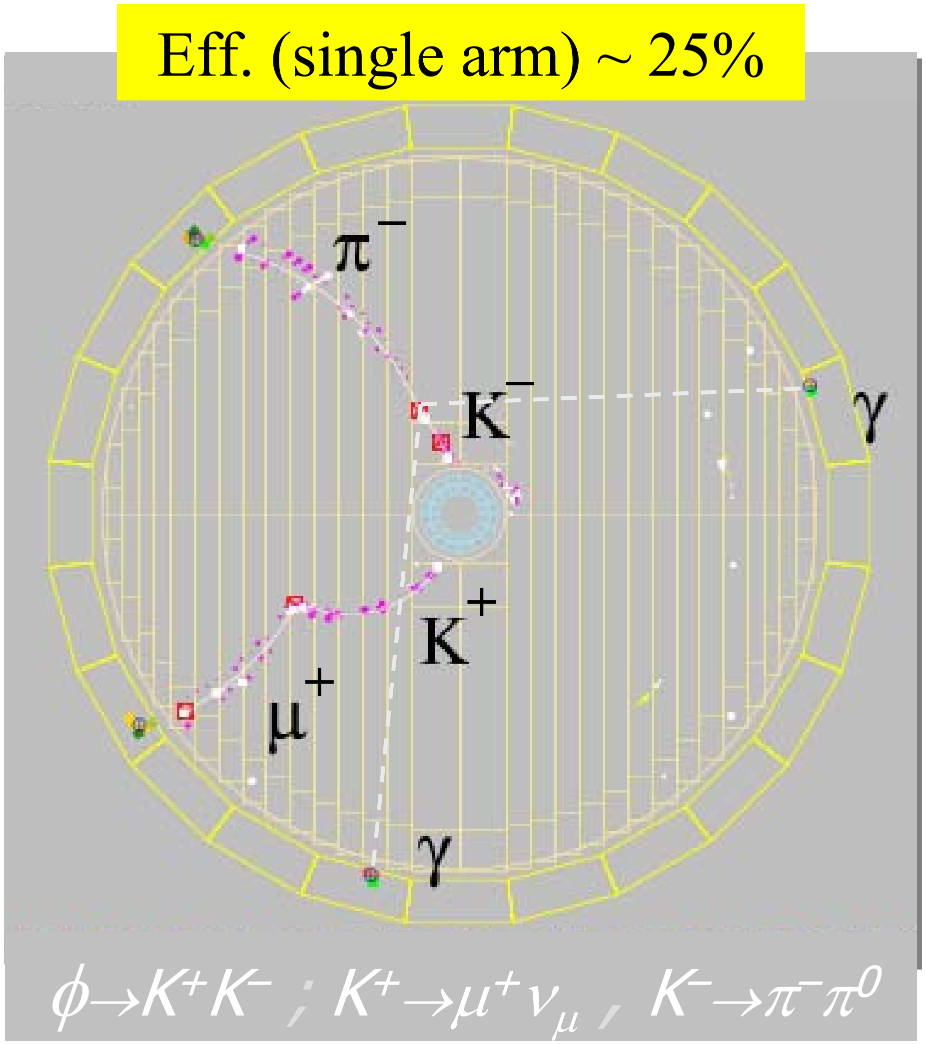
Tagging

- 1 hemisphere **tagging** strategy: $\mu^{\pm}\nu_m$, $\pi^{\pm}\pi^0$
  p^* peaks are used to tag $K^{\pm}$

a) Reject non-K background
b) Fix absolute Timing
c) Satisfy Trigger requirements

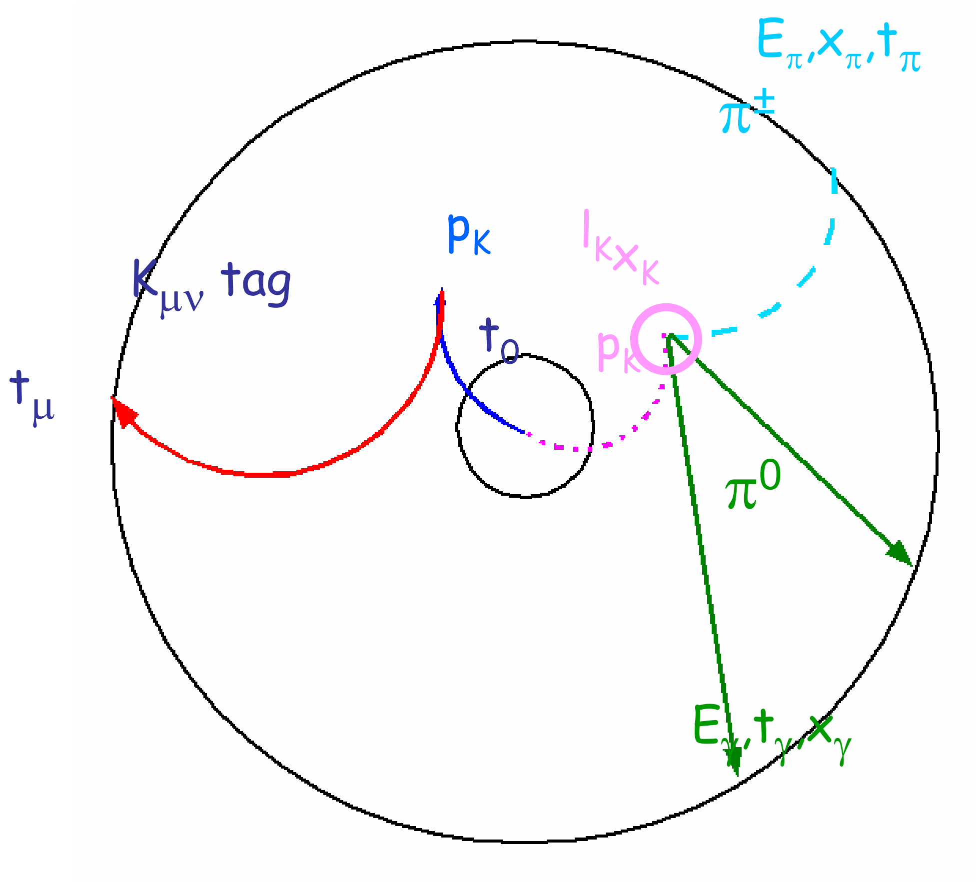


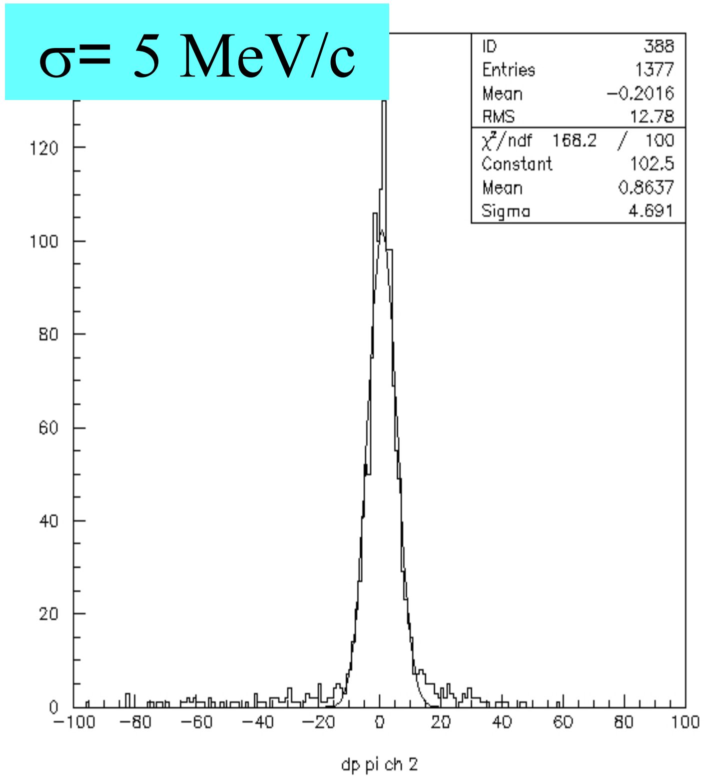
Daughter momentum in **K±** frame



Tracking systematics

Tracking systematics are addressed *directly on data* by extrapolating the tagging signal to the recoiling hemisphere





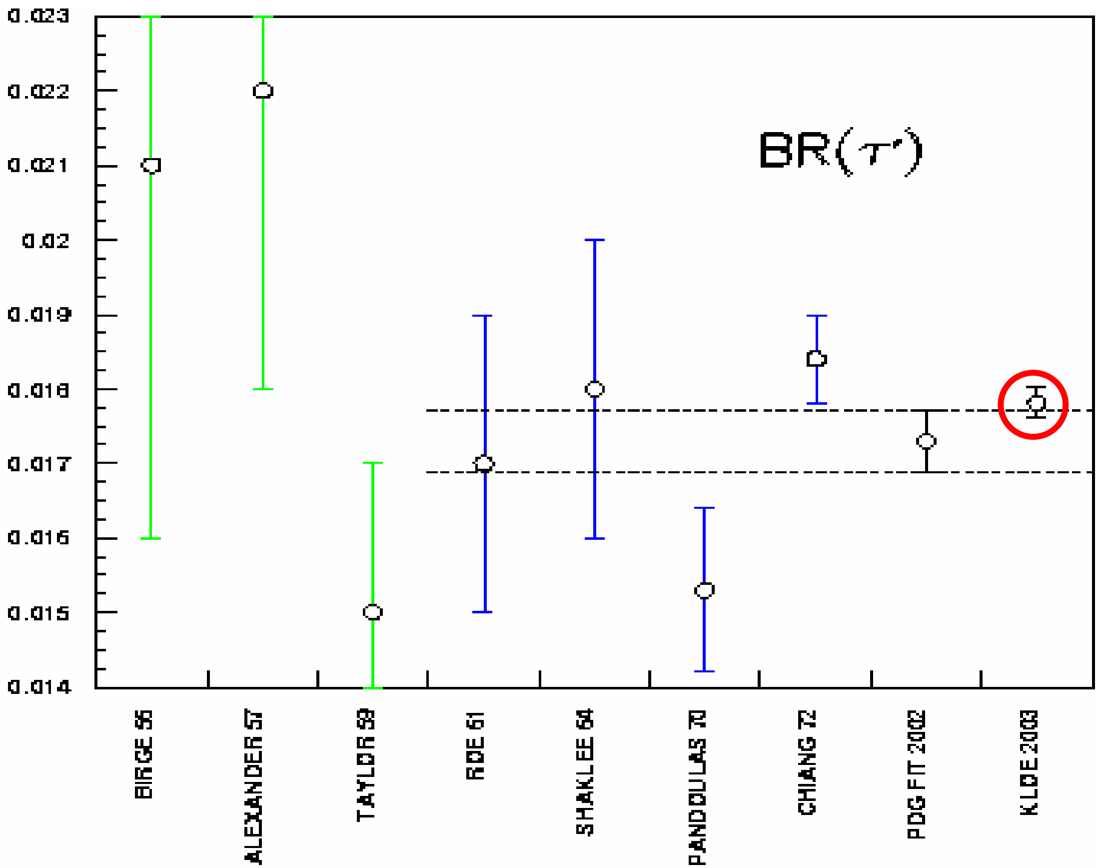
$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ decay

- Extract isospin amplitudes and phase shifts for $K \rightarrow 3\pi$ decays (input to χPT)
- Interesting for direct CPV by measuring charge asymmetry in $K^{\pm}$ rates ($\sim 10^{-8}$) or in the Dalitz plot slopes (10^{-6} up to 10^{-3}, model dependent)

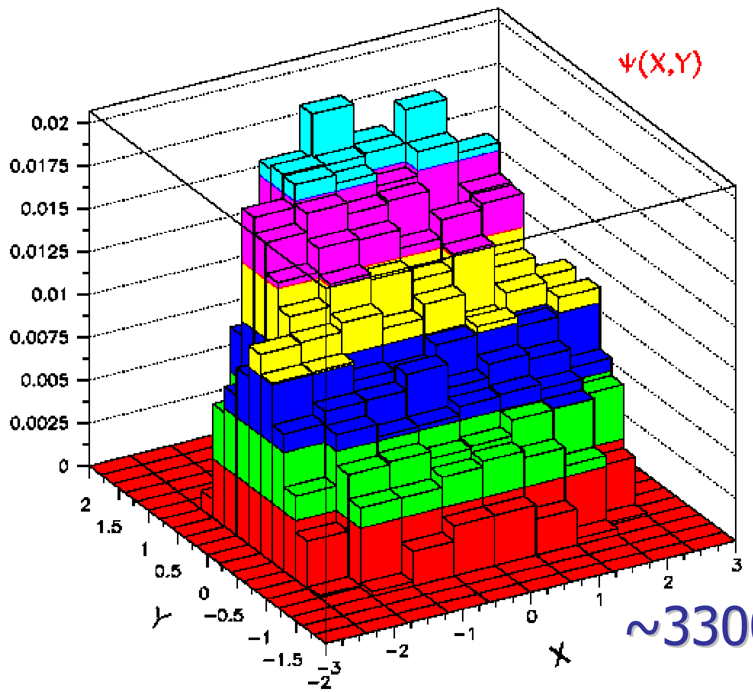
*Based on **441**pb^{-1}*
'01 + '02 DATA

KLOE **BR($K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$)**
(1.781 ± 0.013 ±0.016)%
hep-ex 0307054

PDG '02 fit (1.73 ± 0.04)%



$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ decay: Dalitz plot parameters



~330000 τ′

$$Y \propto T^*(\pi^{\pm})\ ,\ X \propto T^*(\pi^0\pi^0)$$

Fit to Dalitz plot:

$$F(X,Y) = 1 + \boldsymbol{g}Y + \boldsymbol{h}Y^2 + \boldsymbol{k}X^2$$

	KLOE (187 pb^{-1})	PDG '02	ISTRA('03)
g	0.585±0.010 ±0.012	0.652±0.031	0.627±0.004 ±0.010
h	0.030±0.010 ±0.013	0.057±0.018	0.046±0.004 ±0.012
k	0.0064±0.0026 ±0.0018	0.0197±0.0054	0.001±0.001 ±0.002

$K^{\pm} \to \pi^0\pi^0 e^{\pm}\nu$ ($K_{\varepsilon 4}'$)

- χ_{PT} allows to extract $|F_{00}|$ form factor from the decay width
- Test of **$\Delta I = 1/2$** rule and Bose statistics

$$\Gamma(K_{e4}') \cong 0.80 \cdot \left|V_{us} F_{00}\right|^2 \times 10^3 \text{ sec}^{-1}$$

signal extracted from kinematic fit to previous data

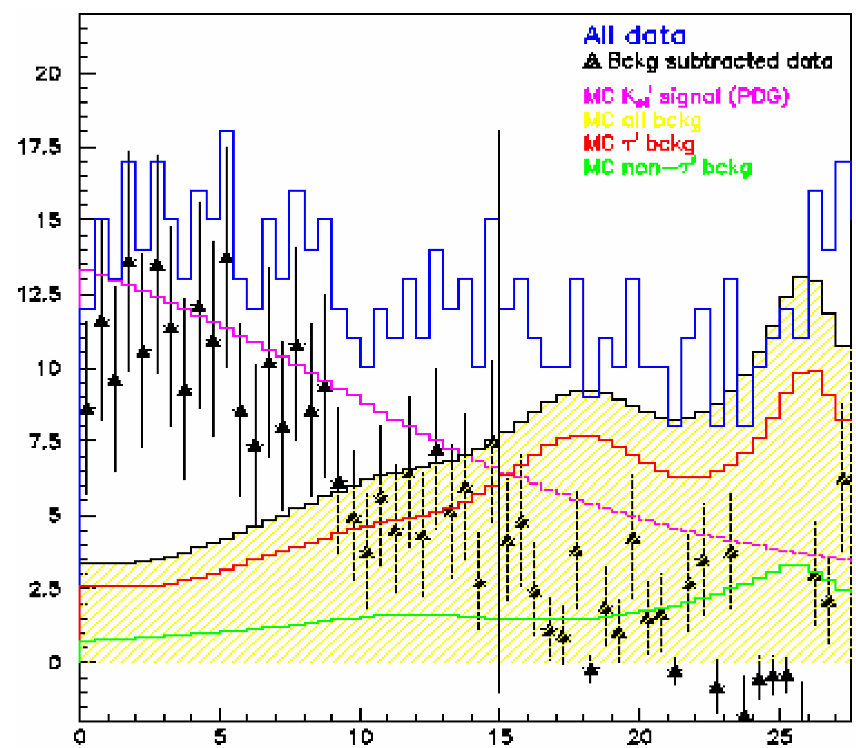
KLOE preliminary

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

BR(K_{e4}') = ($2.43 \pm 0.20 \pm 0.22$) $\times 10^{-5}$

PDG fit: (2.1 ± 0.4) $\times 10^{-5}$

Best measurement: (2.54 ± 0.89) $\times 10^{-5}$



χ^2 from kinematic fit

V_{us} from $K_{\ell 3}$ decays

$$\Gamma(K_{e3}) = \frac{G_F^2 m_K^5}{192\pi^3} C_K^2 |V_{us}|^2 |f_+^{K\pi}(0)|^2 I_K(m_K^2, m_\pi^2, m_\ell^2, \tilde{f}_+^{K\pi}(q^2))$$

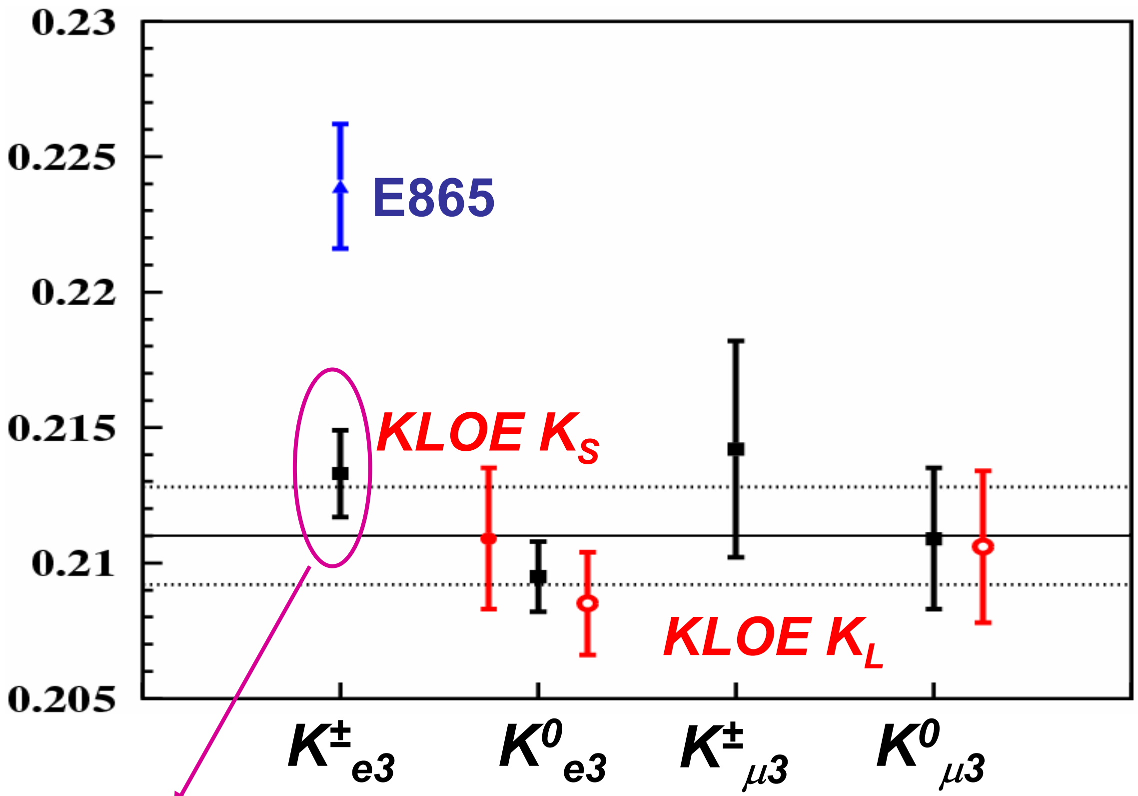
measuring
$BR(K_{l3})/\tau_K$

provided by the theory
CVC+SU(3) $\rightarrow$ $f^{K\pi}(0) = 1$

measuring q^2 evolution of the form factor:

$$f_x^{K\pi}(q^2) = f_x^{K\pi}(0) \cdot \left(1 + \frac{\lambda_+^{K\pi}}{m_\pi^2} q^2\right)$$

The observable is: $|V_{us}||f_+(0)|$



KLOE will have BR(K^+_{e3}) soon

$$\frac{\Delta|V_{us}|}{|V_{us}|} = 0.5\left(\frac{\Delta BR_{K_{e3}}}{BR_{K_{e3}}} + \frac{\Delta\tau}{\tau}\right) + 0.05\frac{\Delta\lambda_+}{\lambda_+} + \frac{\Delta f_+(0)}{f_+(0)}$$

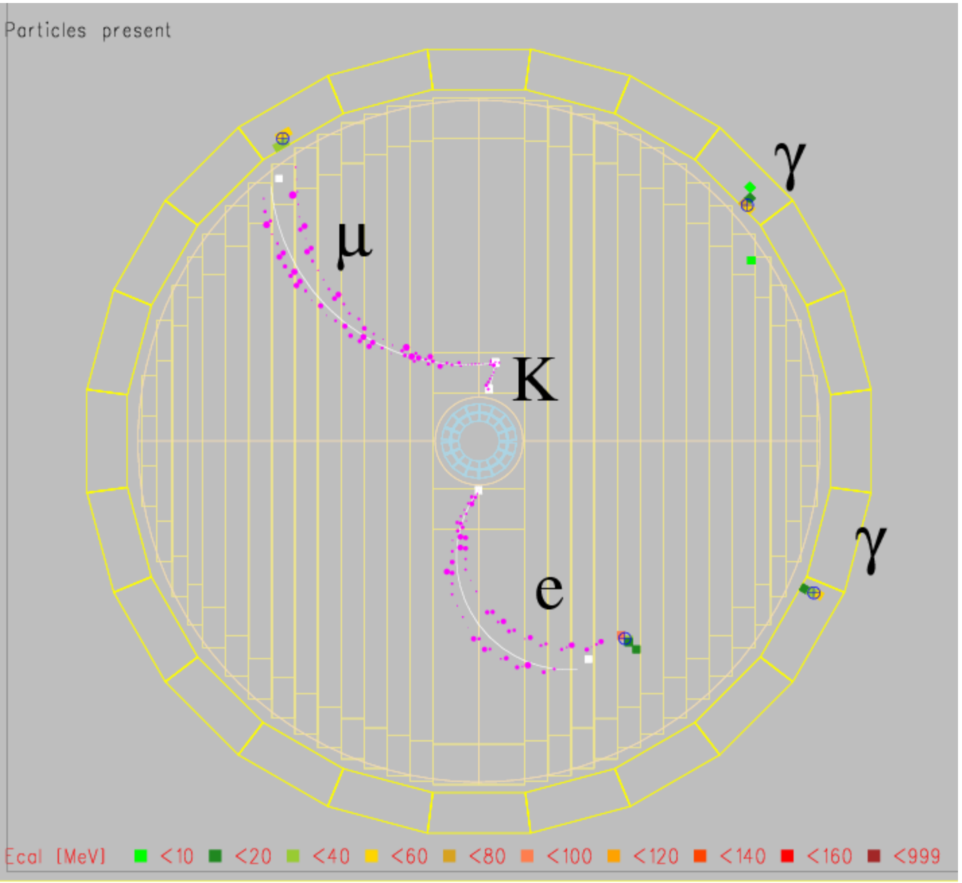
$K^{\pm}_{e3}$	0. 59%	0.22%	0. 86%

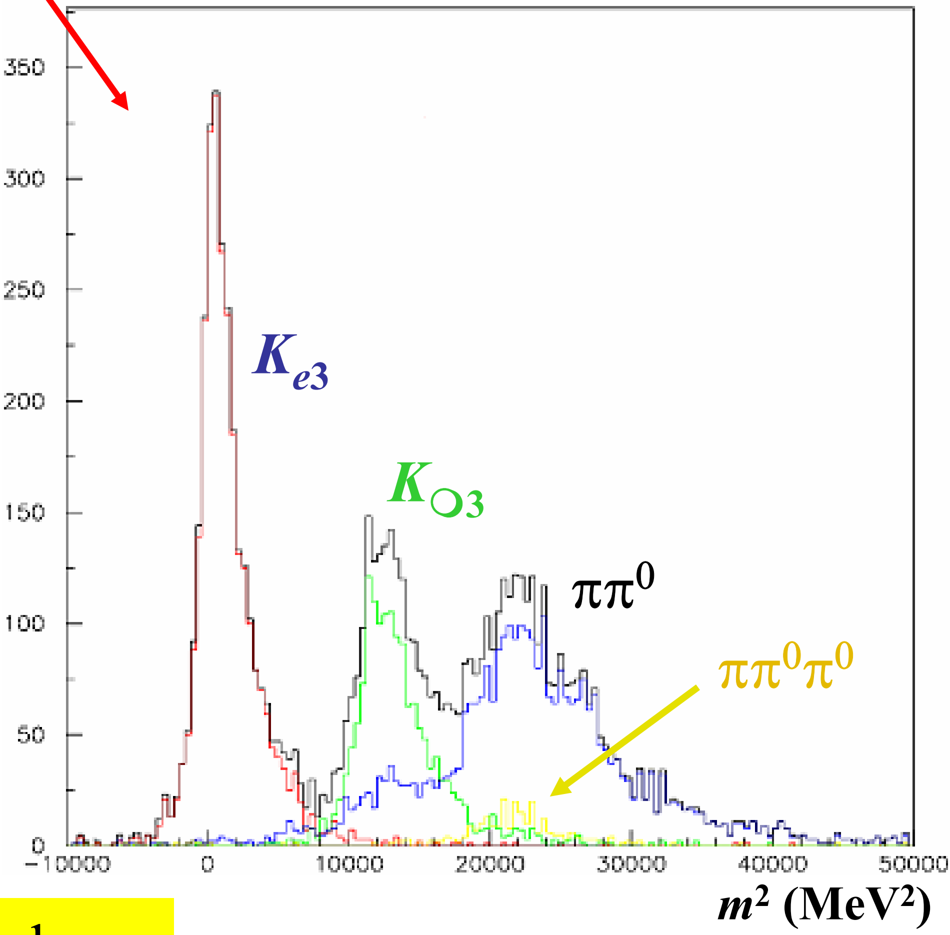
can be reduced…

K_{e3} decays

Event selection by charged daughter mass

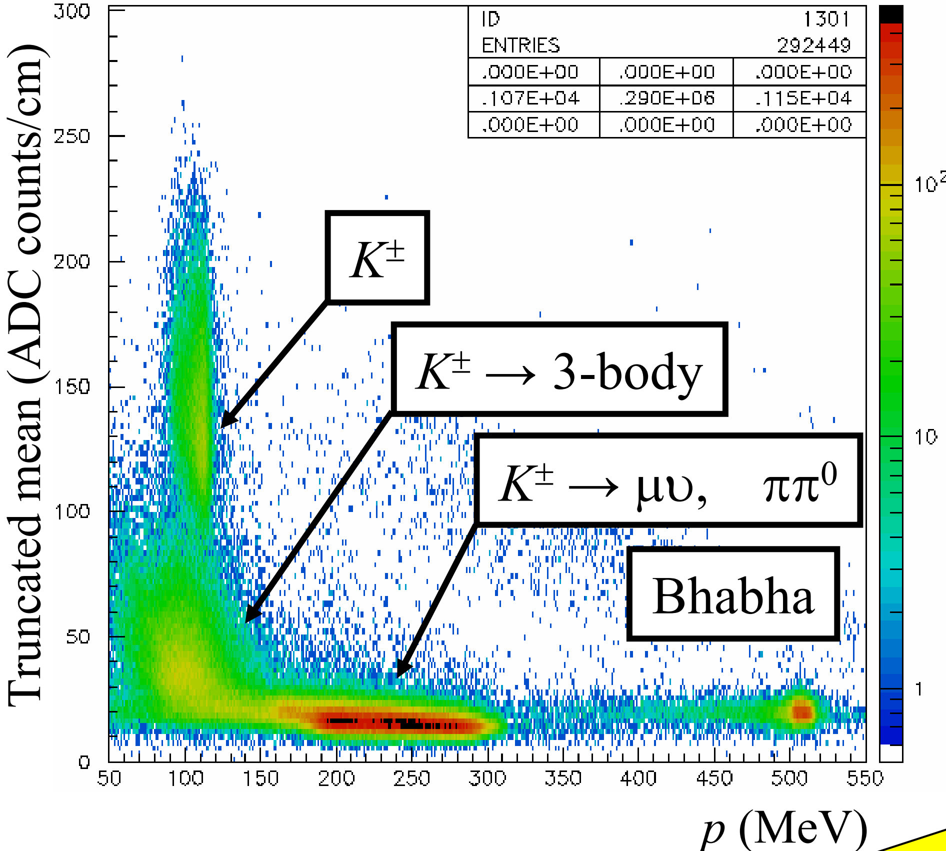
- ***p, L*** from **DC** track
- ***TOF*** from **EmC** with t_0 from π^0 clusters





Dedicated Particle- id still under study

dE/dx in the DC



Work in progress

Improved Monte Carlo Simulation

Ambitious program for MC development and production

Simulated event samples statistically comparable to data

$\phi \rightarrow$ all 452 pb^{-1} at 1:5 scale ~300M events

$\phi \rightarrow K_S K_L$ 452 pb^{-1} at 1:1 scale ~500M events

Comprehensive upgrades
Both MC executable and production procedure affected:

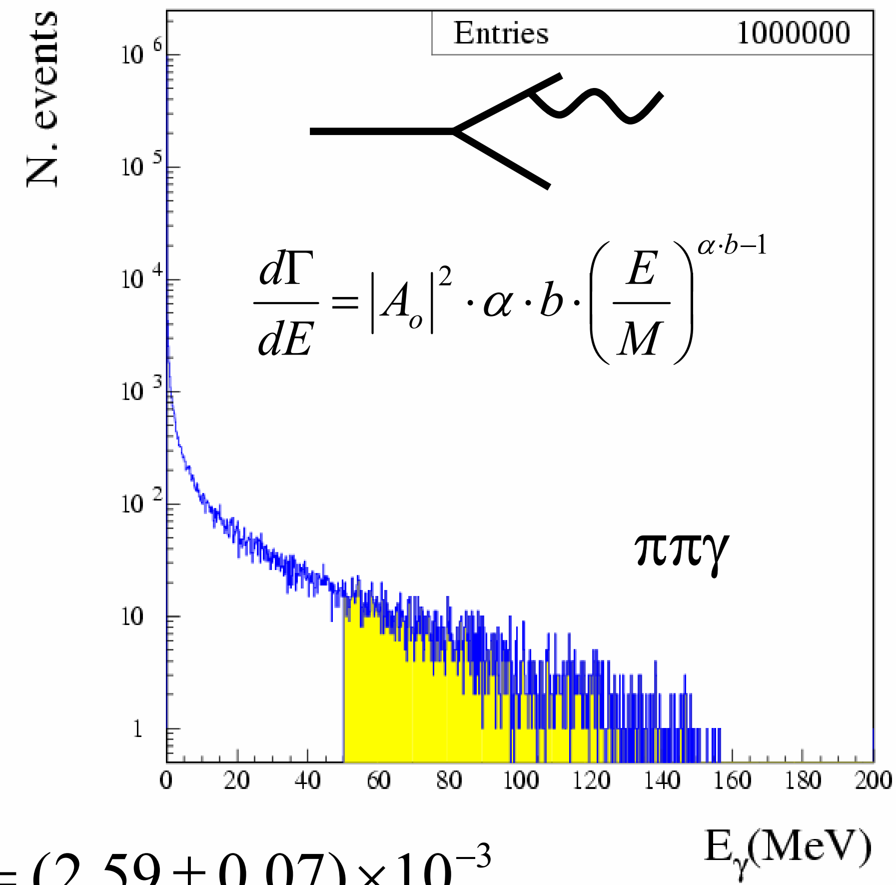
- State-of-the-art detector simulation
- Inclusion of accidental activity from machine background
- MC DST's to provide transparent user interface

Each run in data set individually simulated

- $\sqrt{s}$, $\mathbf{p}_\phi$, $\mathbf{x}_\phi$, background, dead wires, trigger thresholds…

Radiative corrections

New MC generators for ππ and Ke3 decays including radiated photon, without any cutoff on the energy.
The fraction of events in the tail is in agreement with present experimental knowledge.



$N(E_\gamma > 50\ MeV)/N_{TOT} = 2.6 \times 10^{-3}$

$$K_S \to \pi\pi\gamma(> 50\ MeV) / K_S \to \pi\pi = (2.59 \pm 0.07) \times 10^{-3}$$

A clear definition of the treatment of radiative corrections is *needed* for V_{US}.

$$\Gamma(K_{e3}) \to \Gamma(K_{e3}) \cdot (1+\delta) \qquad \delta = \pm 1\%$$

$$|V_{us}|^2 |f_+(0)|^2 \propto \Gamma(K_{e3})$$

KLOE Agenda for the near future

- Finalize studies on *present data set* to get

  Improved K_S *semileptonic decay rate and asymmetry*

  Competitive measurement/limit on $K_S \rightarrow 3\pi$

  K_L *absolute branching ratios* to better than 1%

  Competitive measurement of K_L *lifetime*

  Competitive measurement of $K^{\pm}$ *lifetime*

  V_{us}, V_{us}, V_{us}

- Start new long data taking with higher luminosity → 1–2 fb^{-1}

  Improve all above

  Interferometry measurements

  Measure *CPV* parameters in K_L decays