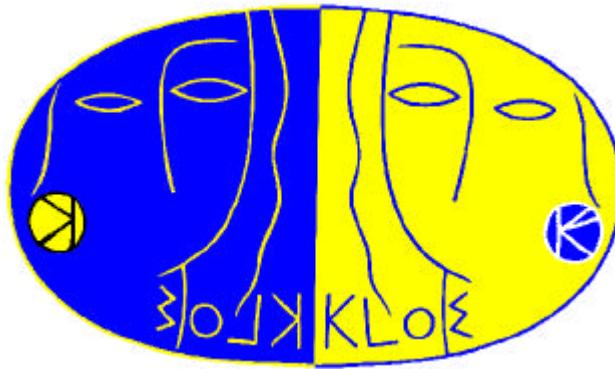




Perspectives of measuring V_{us} at KLOE



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(INFN Roma)
for the KLOE Collaboration

International Workshop on "Quark-Mixing, CKM Unitarity"
Heidelberg 19-20 Sept 2002

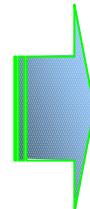
Kaon Physics at the **F** - factory DAFNE



$$e^+e^- \rightarrow f(1020) \rightarrow K\bar{K}$$

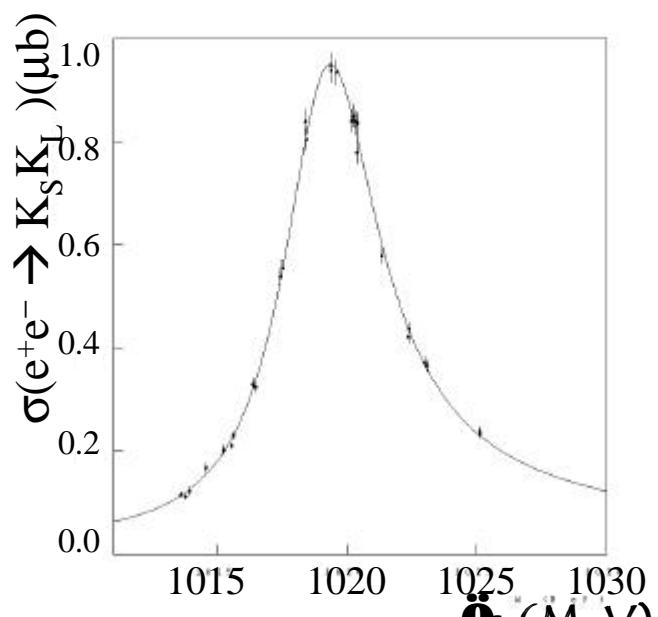
- very clean environment
- pure $K_S K_L$ and $K^+ K^-$ beams
almost monochromatic ($P_\phi \approx 13 \text{ MeV}/c$)
- kaon momentum precisely known
thanks to kinematics enclosure of the event

$$\begin{aligned} BR(f \rightarrow K^+ K^-) &= 49.2\% \\ BR(f \rightarrow K^0 \bar{K}^0) &= 33.8\% \end{aligned}$$



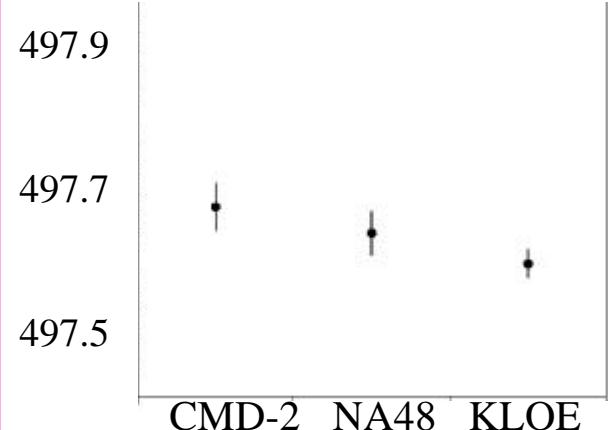
tagging

$$\vec{P}_O = \vec{P}_K + \vec{P}_{\bar{K}} \quad \left\{ \begin{array}{l} P_{K0} \gg 110 \text{ MeV}/c \\ P_{K\pm} \gg 125 \text{ MeV}/c \end{array} \right.$$



$$\begin{aligned} d\sigma_K &= 0.004 \\ dW_{DAFNE} &= 1 \text{ MeV} \end{aligned}$$

Neutral kaon mass (MeV/c^2)



The KLOE experiment measures:

$$m_K = 497.574 \pm 0.005_{\text{stat}} \pm 0.020_{\text{syst}} \text{ MeV}$$



The tagging

Neutral kaons are produced in a pure quantum state ($J^{PC}=1^{--}$) :

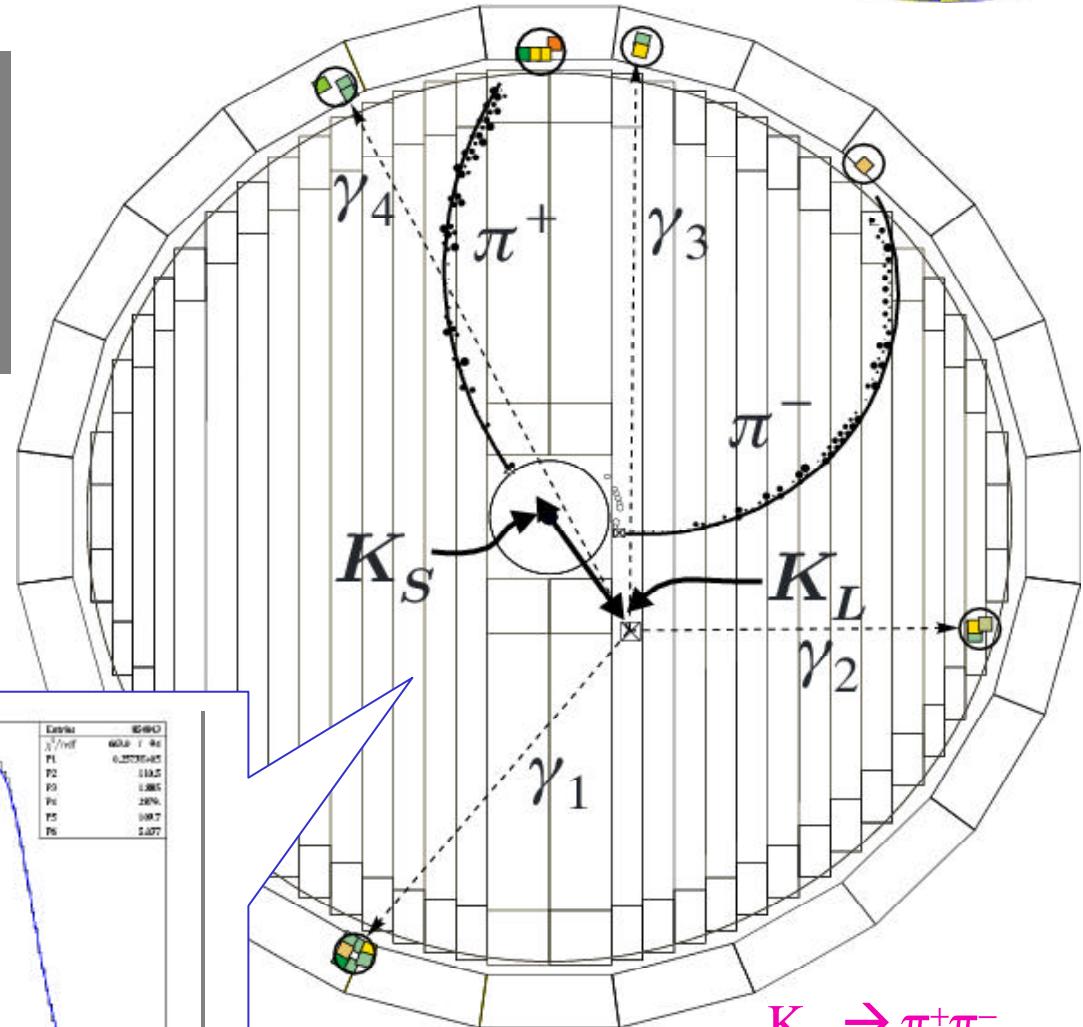
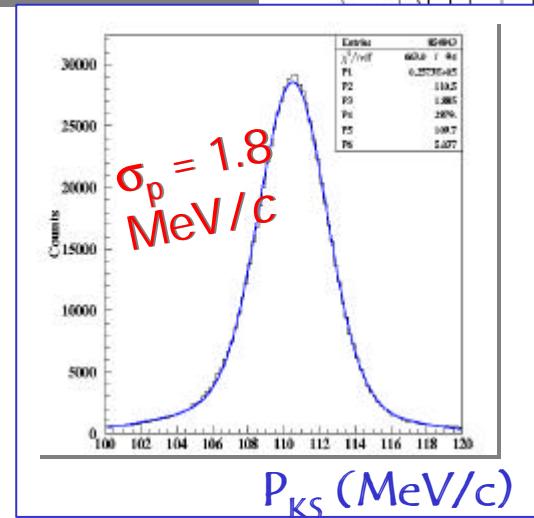


(contamination from $K_S K_S, K_L K_L < 10^{-9}$)

detection of a $K_S (K_L)$ guarantees the presence of a $K_L (K_S)$ with known momentum and direction

$$\vec{P}_{KL} = \vec{P}_\Phi - \vec{P}_{KS} \quad \rightarrow$$

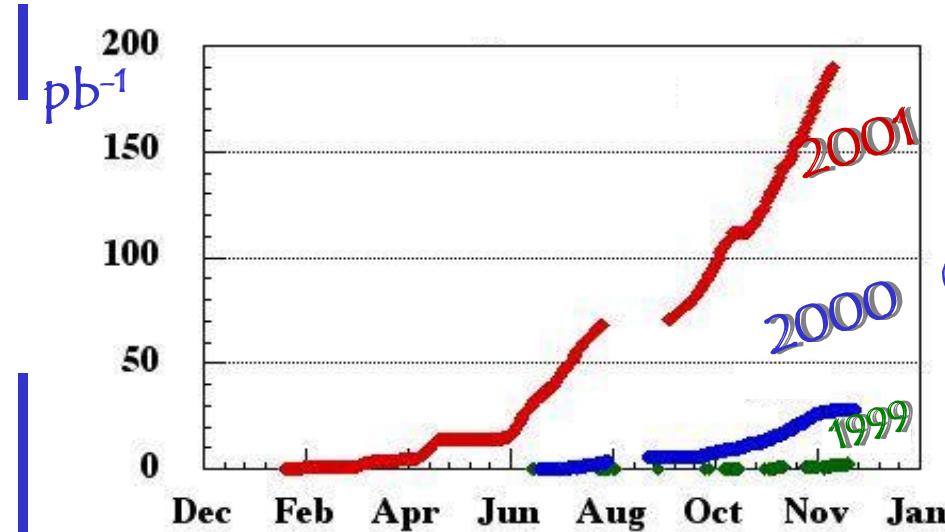
measured run by run
with $\sigma_p \approx 2.5 \text{ MeV}/c$



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

$$K_L \rightarrow \pi^0 \pi^0$$

KLOE Integrated Luminosity



(190 pb⁻¹ → 5.7 × 10⁸ f)
analysis in progress
(20 pb⁻¹ → 7.5 × 10⁷ f)
published results

2002
~ 240 pb⁻¹ up to now and cleaner situation due to machine background reduction of a factor 2,3
➤ L @ peak (2002) = $7 \cdot 10^{31}$ (cm⁻² s⁻¹)
L @ peak (2001) = $5 \cdot 10^{31}$ (cm⁻² s⁻¹)

→ ~ 300 pb⁻¹ at run end

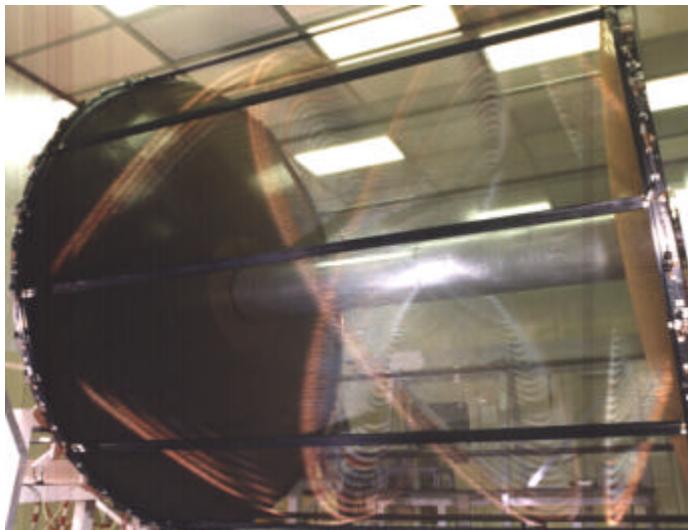
1. 5 × 10⁶ K⁺K⁻ / pb⁻¹
10⁶ K_LK_S / pb⁻¹

The KLOE detector



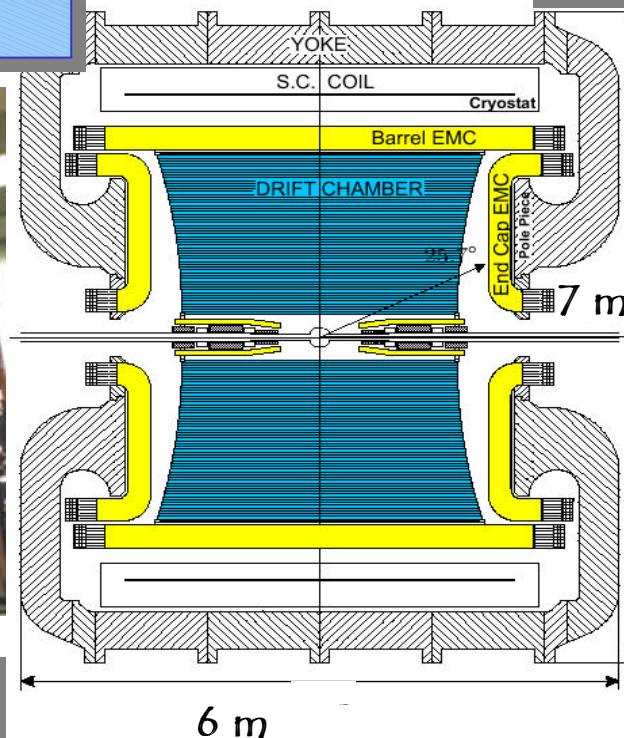
Drift Chamber

- ◊ 4 m diameter × 3.3 m length
- ◊ 90% helium, 10% isobutane
- ◊ 12582/52140 sense/tot wires
- ◊ All-sereo geometry



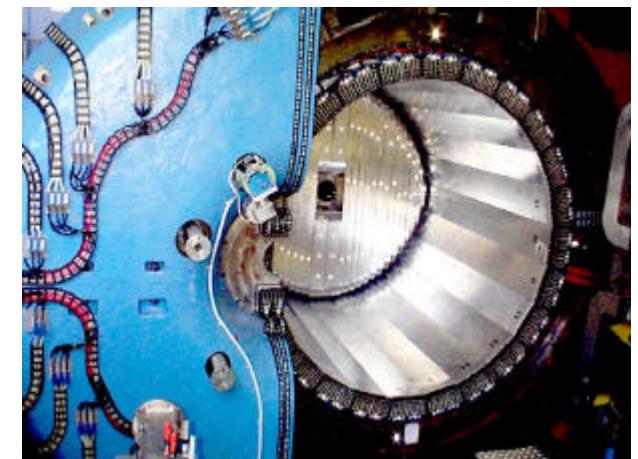
$$\begin{aligned}\mathbf{s}_{rf} &= 150 \text{ mm } \mathbf{s}_z = 2 \text{ mm} \\ \mathbf{s}_v &= 3 \text{ mm } \mathbf{s}_p/p = 0.4 \%\end{aligned}$$

$$\begin{aligned}\mathbf{l}_s &= 0.6 \text{ cm} \\ \mathbf{l}_L &= 340 \text{ cm} \\ \mathbf{l}_\pm &= 95 \text{ cm}\end{aligned}$$



Electromagnetic Calorimeter

- ◊ Lead/scintillating fiber
- ◊ 98% coverage of solid angle
- ◊ 88 modules (barrel + end-caps)
- ◊ 4880 PMTs (two side read-out)



$$\begin{aligned}\mathbf{s}_E/E &= 5.4\% / \sqrt{E(\text{GeV})} \\ \mathbf{s}_t &= 54 \text{ ps} / \sqrt{E(\text{GeV})} \\ &\oplus 50 \text{ ps(cal)}\end{aligned}$$

V_{us} from K_{e3} decays



$$\Gamma(K_{e3}) = \underbrace{\frac{G_F^2 m_K^5}{192\pi^3} C_K^2}_{\text{measuring}} |V_{us}|^2 \underbrace{|f_+^{K\pi}(0)|^2}_{\text{provided by the theory}} I_K(m_K^2, m_\pi^2, m_\ell^2, \tilde{f}_+^{K\pi}(q^2)) \underbrace{\tilde{f}_+^{K\pi}(q^2)}_{\text{measuring } q^2 \text{ evolution of the form factor:}}$$

measuring
 $BR(K_{l3})/t_K$

provided by the theory



measuring q^2 evolution of
the form factor:

$$f_x^{Kp}(q^2) = f_x^{Kp}(0) \cdot \left(1 + \frac{I_+^{Kp}}{m_p^2} q^2 \right)$$

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

Ignoring phase space and form factor differences:

$$\Gamma(K_L \rightarrow \pi e \nu) = \Gamma(K_S \rightarrow \pi e \nu) = 2 \Gamma(K^\pm \rightarrow \pi^0 e^\pm \nu)$$

But:

$$2 \times (2\tilde{A}^+ - \tilde{A}^0) / (2\tilde{A}^+ + \tilde{A}^0) = (3.66 \pm 0.06)\%$$



$SU(2)$ (and $SU(3)_F$)
symmetry breaking effect



Experimental status of K_{e3} decays

$$V_{us} = 0.2196 \pm 0.0026$$

$\Delta V_{us}/V_{us} = 1.18\%$ (PDG '02)

To extract V_{us} from the experimental observable we need:

- ❖ SU(2) and SU(3)_F symmetry breaking corrections
- ❖ radiative corrections

$\frac{\Delta BR}{BR}(\%)$	$\frac{\Delta t}{t}(\%)$	$\frac{\Delta \Gamma}{\Gamma}(\%)$	$\frac{\Delta \lambda_+}{\lambda_+}(\%)$	$\frac{\Delta \lambda_0}{\lambda_0}(\%)$
K_{e3}^+				
1.2	0.2	1.22	4.5	-
$K_{\mu 3}^+$				
2.5	0.2	2.5	12.2	19.7
K_{e3}^0				
0.7	0.8	1.06	4.7	-
$K_{\mu 3}^0$				
0.9	0.8	1.20	14.7	24.0

$$\frac{\Delta |V_{us}|}{|V_{us}|} = 0.5 \left(\underbrace{\frac{\Delta BR_{K_{e3}}}{BR_{K_{e3}}} + \frac{\Delta t}{t}}_{K_{e3}^\pm \quad 0.59\%} \right) + 0.05 \underbrace{\frac{\Delta I_+}{I_+}}_{0.22\%} + \underbrace{\frac{\Delta f_+(0)}{f_+(0)}}_{0.86\%}$$



Both K^\pm and K^0 must be measured



Measuring V_{us} at KLOE

KLOE can improve the accuracy in the knowledge of $\Gamma(e3)$ measuring:

- both charged and neutral kaons absolute BR's with the same detector
- directly the kaon partial decay width

Traditional method:

- ◊ measurement of $\mathbf{G} = 1/\mathbf{t}$
- ◊ measurement of $\text{BR}(e3)$



$$\Gamma(e3) = \text{BR}(e3) \times \mathbf{G}$$

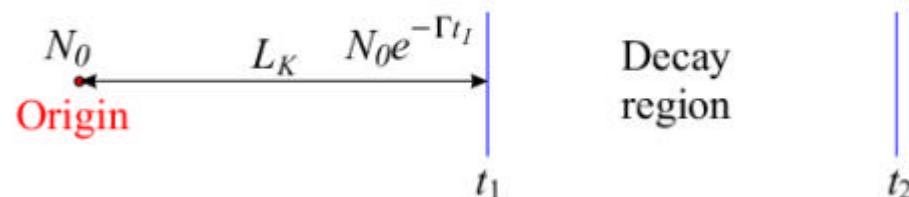
$$\frac{d\Gamma(e3)}{\Gamma(e3)} = \sqrt{\left(\frac{dt}{t}\right)^2 + \left(\frac{d(BR(e3))}{BR(e3)}\right)^2}$$

KLOE :

- ◊ by the tag count the number of K produced , N_{KL}
- ◊ count the number N_{e3} of semileptonic decays in the decay region

$$\Gamma(e3) = (\mathbf{D}N_{e3}/\mathbf{Dt})/N_{KL}$$

\mathbf{G} is a correction & dt/t dependence reduced by a factor » 5



Charged kaons



- Tagging is provided by $K \rightarrow \mu\nu$, $K \rightarrow \pi\pi^0$ decays (BR~85%) selected using only Drift Chamber information.

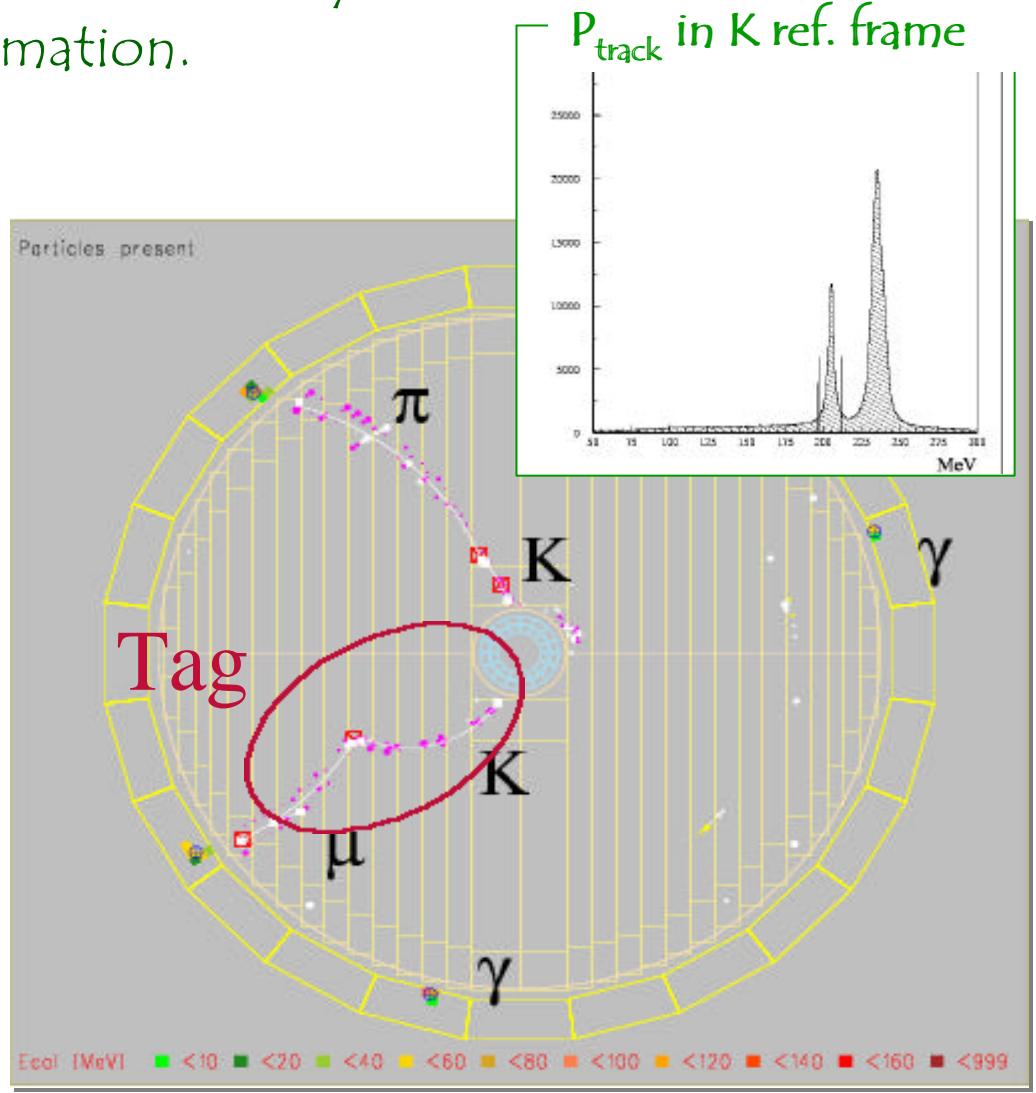
$$\Rightarrow e_{mn}^{TAG} \approx e_{pp^0}^{TAG}$$

- From MC: $e_{mn}^{TAG} \approx 55\%$

- e_{mn}^{TAG} can be estimated directly from Data using the redundant calorimetric information ($N_\gamma = 0$).

With 200 pb^{-1} :

$$\frac{\Delta e_{TAG}}{e_{TAG}} \propto \frac{1}{\sqrt{N_{mn}}} \approx 0.1\%$$



K_{e3}^\pm signal selection

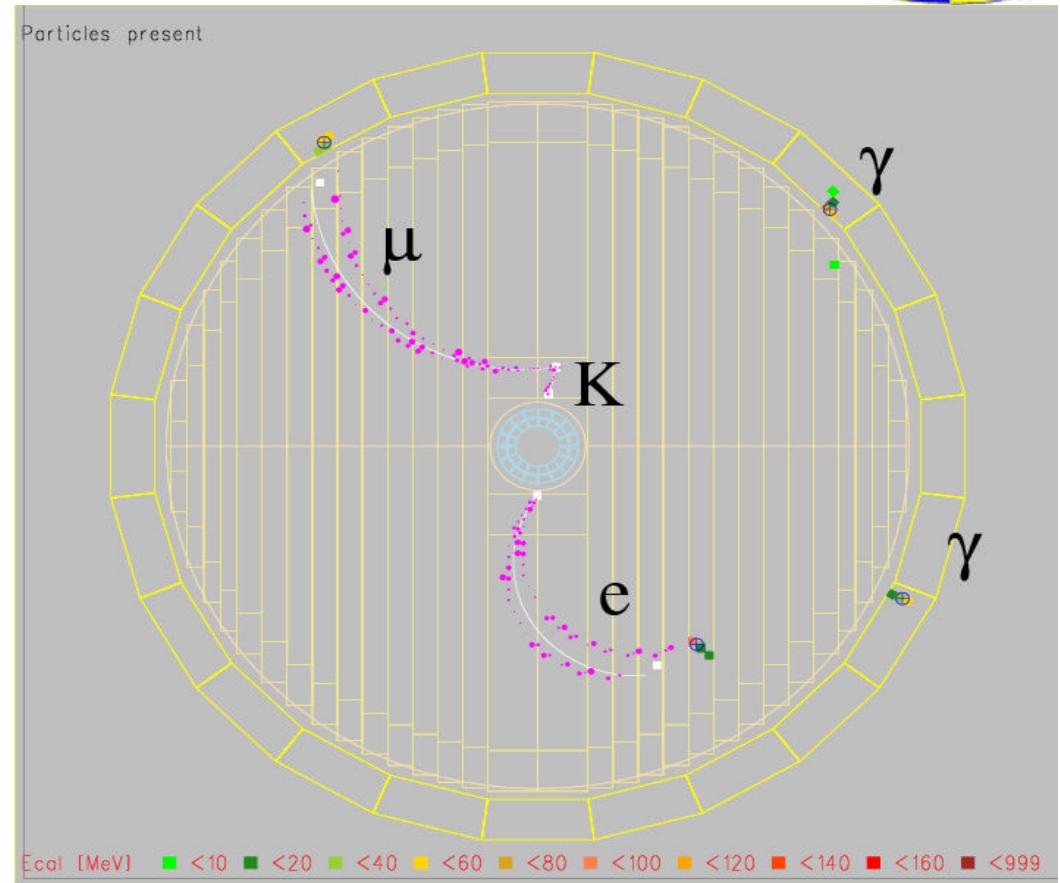


- ✓ Tag on one side
- ✓ Vertex in DC
- ✓ ToF selection
- ✓ π^0 in EMC

17 pb⁻¹

	K_{e3}^\pm (yield)	$\varepsilon_{sele}(K_{e3}^\pm)(\%)$
K_μ^\pm TAC	21 662	34.4 ± 0.6
$K_{\pi\pi^0}^\pm$ TAC	3 872	32.7 ± 1.3

Preliminary



$$N_{K_{e3}^\pm} \approx 2000/\text{pb}^{-1} \Rightarrow \underbrace{0.4 \times 10^6}_{200 \text{ pb}^{-1} \text{ (2001 run)}} + \underbrace{0.6 \times 10^6}_{\gg 300 \text{ pb}^{-1} \text{ (2002 run)}}$$

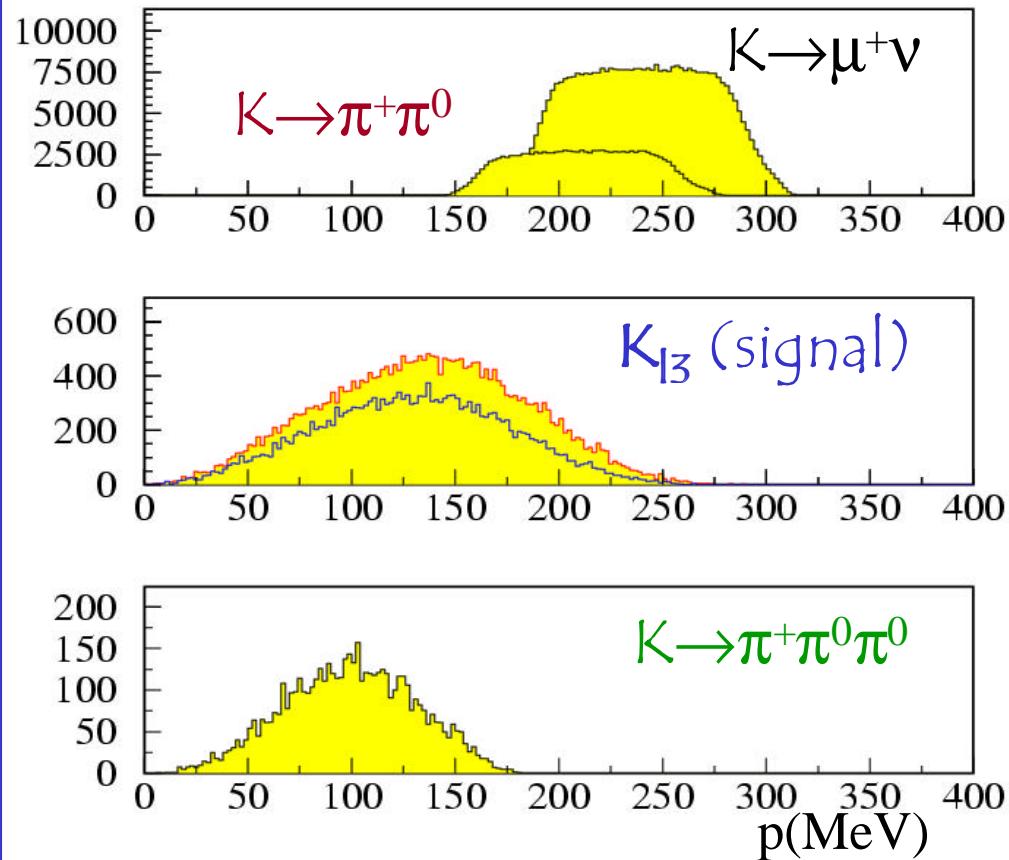


K^\pm_{e3} signal efficiency

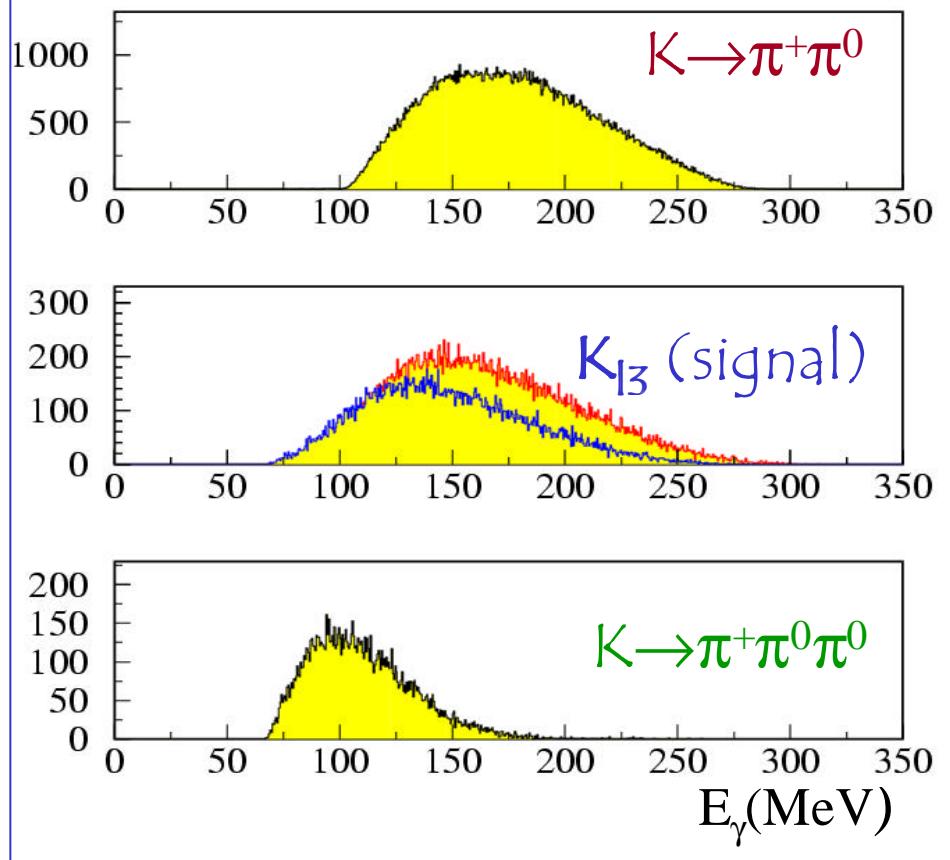
Most of the efficiencies can be evaluated directly from data using control samples \Rightarrow method used for $G(K_s \rightarrow p^+ p^- (g)) / G(K_s \rightarrow p^0 p^0)$

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Track + Vertex fit



p^0 cluster



Neutral kaons



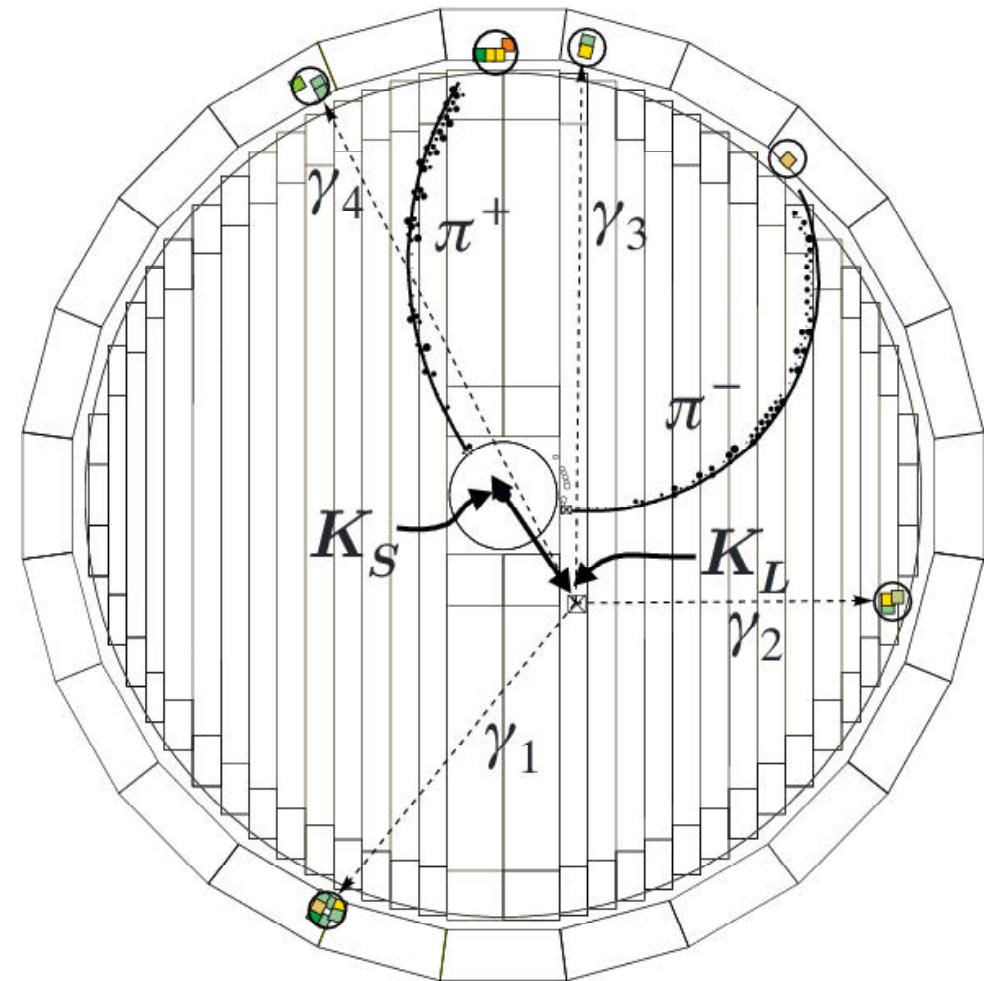
- K_L Tagging is provided by $K_s \rightarrow \pi^+ \pi^-$ decays selected using only Drift Chamber information.

- From MC: $e_{p^+ p^-}^{TAG} \approx 70\%$

- $e_{p^+ p^-}^{TAG}$ can be estimated directly from data using a sample with K_L interacting in EMC (K_L - crash) and requiring 2 tracks

With 200 pb^{-1} :

$$\frac{\Delta e_{TAG}}{e_{TAG}} \propto \frac{1}{\sqrt{\tilde{N}_{p^+ p^-}}} \approx 0.1\%$$

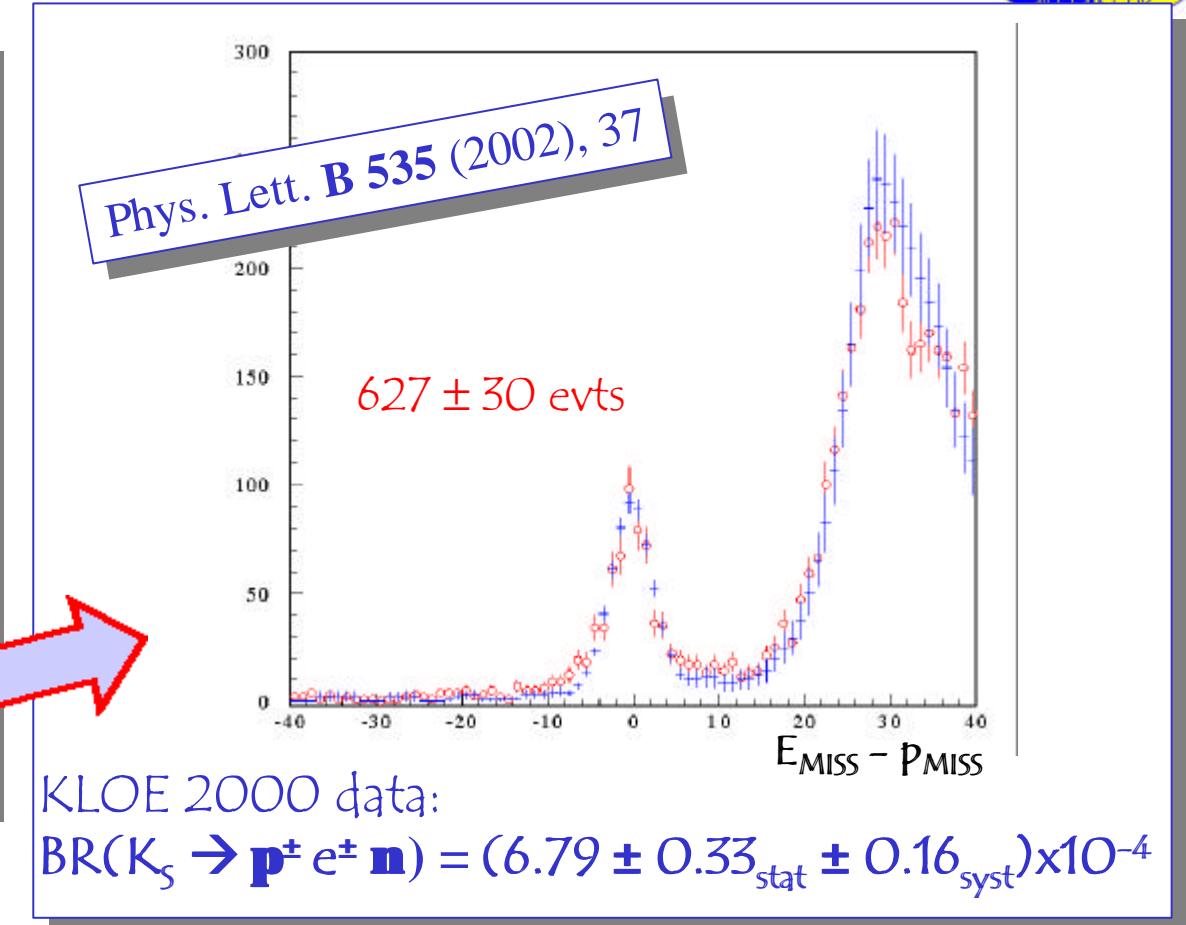


K^0_{e3} signal selection



- ✓ Tag on one side
- ✓ Vertex in DC fiducial volume
- ✓ Invariant mass cut
- ✓ ToF selection

➤ Procedure already used for $K_s \rightarrow p^\pm e^\pm n$:



$$N_{K^0_{e3}} \approx 3 \times 10^4 / \text{pb}^{-1} \Rightarrow \underbrace{6 \times 10^6}_{200 \text{ pb}^{-1} \text{ (2001 run)}} + \underbrace{9 \times 10^6}_{\gg 300 \text{ pb}^{-1} \text{ (2002 run)}} (\sim 1.5 \times 10^4 K_s \rightarrow p^\pm e^\pm n)$$



Measuring \mathbf{I}_+

K^0_{e3} $I_+ = 0.0245 \pm 0.0012_{stat} \pm 0.0022_{syst}$ (CPLEAR) 365 kevts

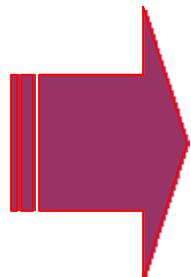
6 Mevts

@KLOE (200 pb⁻¹)
 $\sigma_{stat} \approx O(10^{-4})$

K^\pm_{e3} $I_+ = 0.0293 \pm 0.0015_{stat} \pm 0.002_{syst}$ (ISTRAP) 130 kevts
 $I_+ = 0.0278 \pm 0.0017_{stat} \pm 0.0015_{syst}$ (KEK-E246) 100 kevts

0.4 Mevts

@KLOE (200 pb⁻¹)
 $\sigma_{stat} \approx O(10^{-3})$



KLOE can improve the actual measurements of I_+ using both K^0_{e3} and K^\pm_{e3} decays

Conclusions and Outlook



- ❖ Next experimental improvement on ΔV_{us} from K_{l3} BR's and **G(e3)** and **I₊** (we will do better than the accuracy on the theoretical correction)
- ❖ KLOE has the capability of measuring absolute BR's both for neutral and charged kaons and the unique feature of measuring directly the partial decay width **G(K_{l3})**
- ❖ Good experimental resolution
- ❖ stat (500 pb⁻¹) ≈ 0.07%
- ❖ syst : to be determined **but** most of them are evaluated with data
⇒ improvements increasing the statistics of the control sample O(0.07%)

DA Φ NE parameters

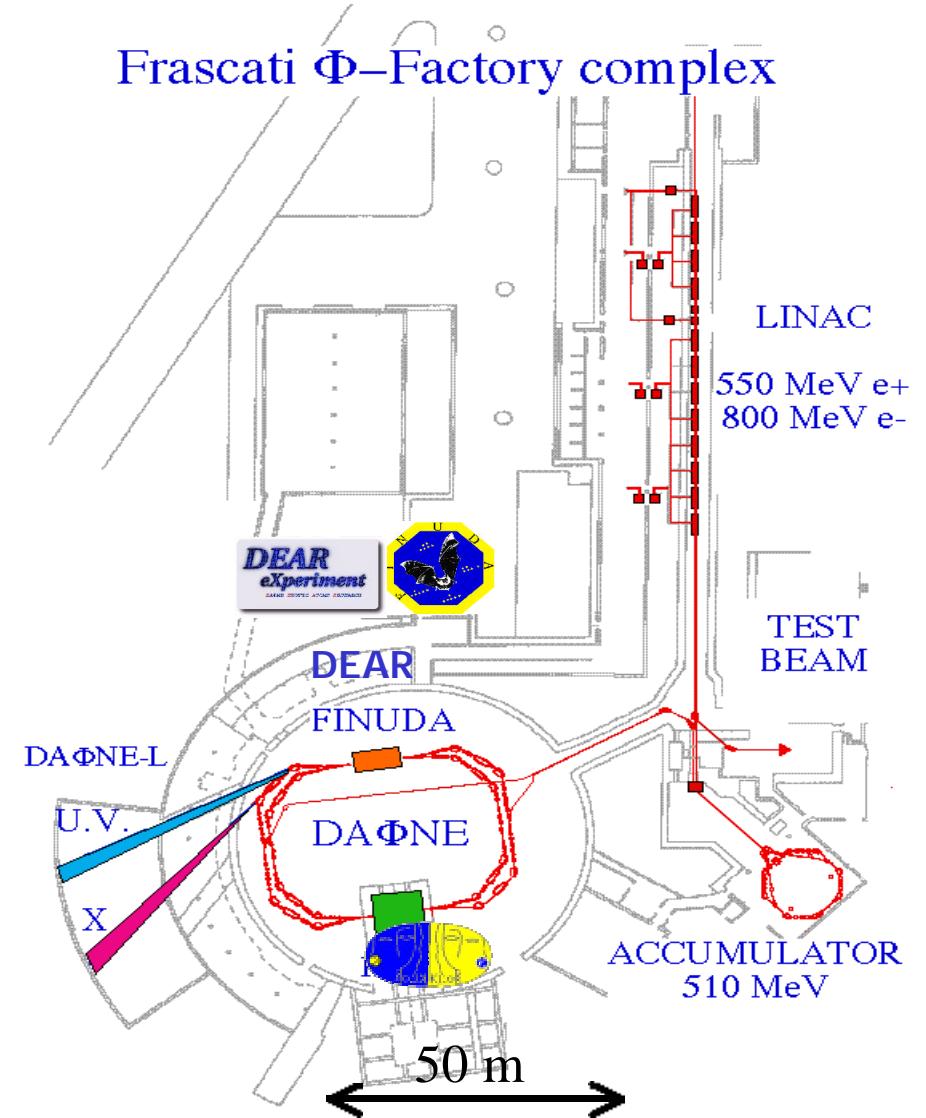


Design parameters

- ◊ Beam energy : 510 MeV
- ◊ Max number of bunches : 120
- ◊ Bunch spacing : 2.7 ns
- ◊ Bunch current : 40 mA
- ◊ Single bunch luminosity : $4 \cdot 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$



$$L = 5 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$$



$\text{BR}(K_S \rightarrow p^\pm e^\pm n)$



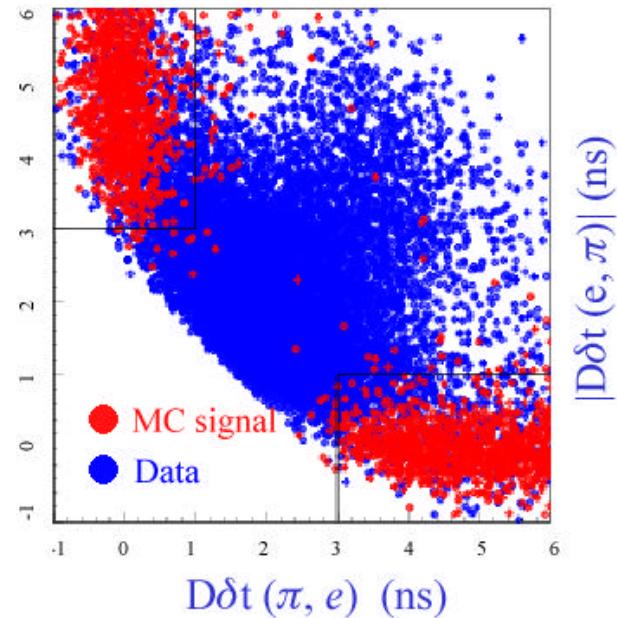
Motivations

◊ if (CPT).and.(ΔS .eq. ΔQ) then

$$\text{BR}(K_S \rightarrow \pi^\pm e^\pm \nu) = \text{BR}(K_L \rightarrow \pi^\pm e^\pm \nu) \times \Gamma_L / \Gamma_S$$

from PDG values = $(6.704 \pm 0.071) \times 10^{-4}$

only one measurement (CMD-2 1999): $(7.2 \pm 1.4) \times 10^{-4}$



Selection

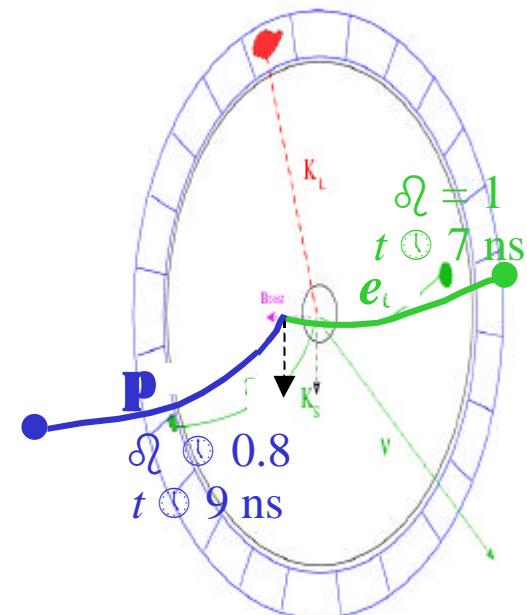
- ❖ K_L -crash.and.charged vertex at IP ($r < 8\text{cm}$, $|z| < 10\text{cm}$) .and.2 tracks with associated EmC clusters
- ❖ invariant mass of the tracks in π hp $M_{\pi\pi} < 490 \text{ MeV}/c^2$ (against background from $K_S \rightarrow \pi^+\pi^-$)
- ❖ π/e identification using time-of-flight
- ❖ $E_{\text{miss}} - |\vec{p}_{\text{miss}}|$

p/e identification using time-of-flight

$$D\delta t(\pi, e) = [t_1^{\text{CLU}} - t_2^{\text{CLU}}] - [L_1/c \beta(\pi) - L_2/c \beta(e)]$$

❖ $|D\delta t(\pi, e)| > 1.5 \text{ ns}$ to reject $K_S \rightarrow \pi^+\pi^-$

❖ Cuts on $D\delta t(\pi, e)$ and $D\delta t(e, \pi)$



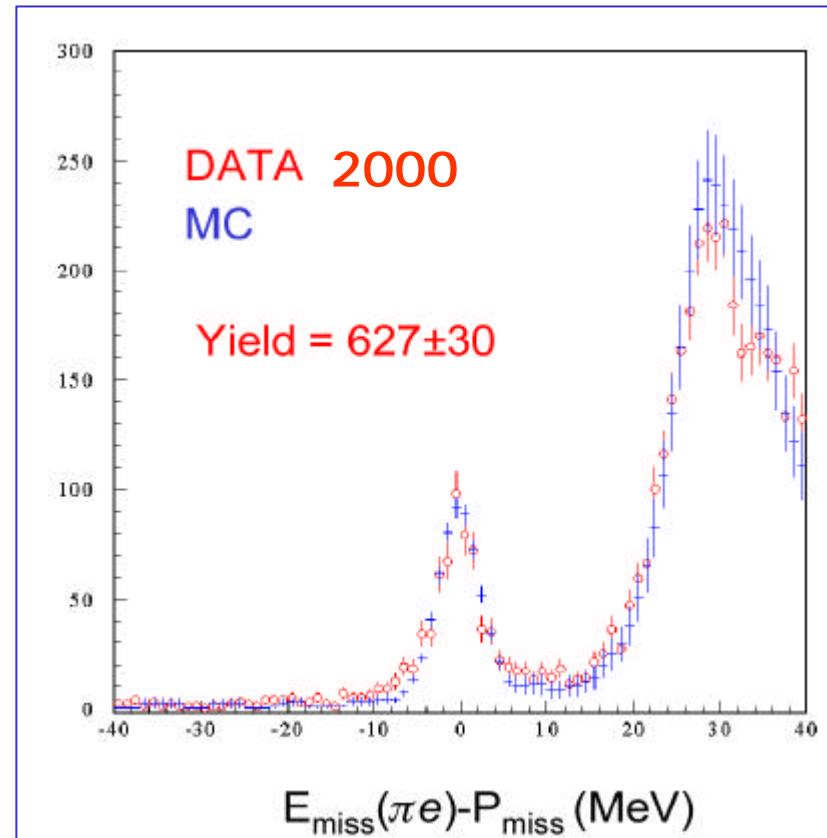
Efficiency evaluation



- ✓ Vertex reconstruction, fiducial cuts and M_{pp} efficiency from MC but also from data $K_L \rightarrow \pi e \nu$ near I.P. (high-purity sample ($> 99.7\%$), by kinematic cuts) and $K_S \rightarrow \pi^0 \pi^0$ to scale MC
- Tracking efficiency for MC and data from $K_S \rightarrow \pi^+ \pi^-$
- ✓ Single-particle t_0 , track-cluster, and trigger efficiencies from data using $K_L \rightarrow \pi e \nu$ near origin and $K_S \rightarrow \pi^+ \pi^-$ but also $\phi \rightarrow \pi^+ \pi^- \pi^0$. MC efficiency scaled accordingly
- ✓ Time of flight ID efficiency from $K_L \rightarrow \pi e \nu$ decays near origin and $K_S \rightarrow \pi^+ \pi^-$

Overall selection efficiency:

$(20.8 \pm 0.4)\%$



Fit to $E_{\text{miss}} - P_{\text{miss}}$ spectrum using MC spectra for signal and $\pi^+ \pi^-$ background
Normalization to $K_S \rightarrow \pi^+ \pi^-$ decays



$\text{BR}(K_S \rightarrow p^\pm e^\pm n)$

CPT and $\Delta S = \Delta Q$ predicts: $\Gamma(K_S \rightarrow \pi^\pm e^\pm \nu) = \Gamma(K_L \rightarrow \pi^\pm e^\pm \nu)$

and then: $\text{BR}(K_S \rightarrow \pi^\pm e^\pm \nu) = \text{BR}(K_L \rightarrow \pi^\pm e^\pm \nu) \times (\Gamma_L / \Gamma_S)$

Using PDG:

$$\text{BR}(K_S \rightarrow p^\pm e^\pm n) = (6.704 \pm 0.071) \times 10^{-4}$$

Result

KLOE 2000 data, $(6.79 \pm 0.33_{\text{stat}} \pm 0.16_{\text{syst}}) \times 10^{-4}$ 627 ± 30 evts

CMD-2 1999, $(7.2 \pm 1.4) \times 10^{-4}$ 75 ± 13 evts

Main contributions to the total error	%
Statistics	4.9
Tracking + vertex efficiency	2.0
Cluster, t_0 , trigger	0.9
TOF selection eff	0.8
Tag eff	0.6
Total	5.9

lower with the
2001 data !!

K_S analysis at KLOE



K_S tagging using time of flight identification of K_L interacting in the EmC (" K_L -crash") selected as a calorimeter cluster with:

- $E_{\text{clus}} > 200 \text{ MeV}$
- $|\cos(\theta_{\text{clus}})| < 0.7$
- $0.195 \leq \beta^* \leq 0.2475$

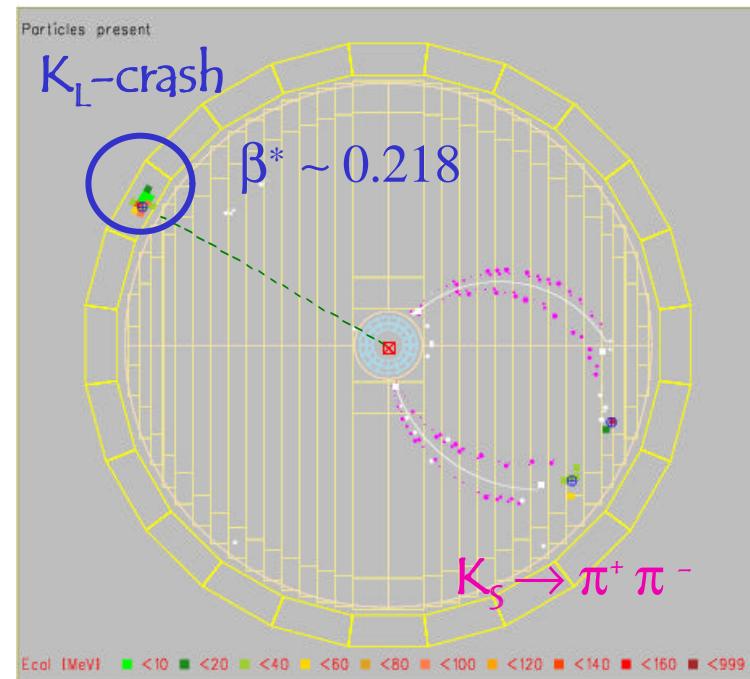
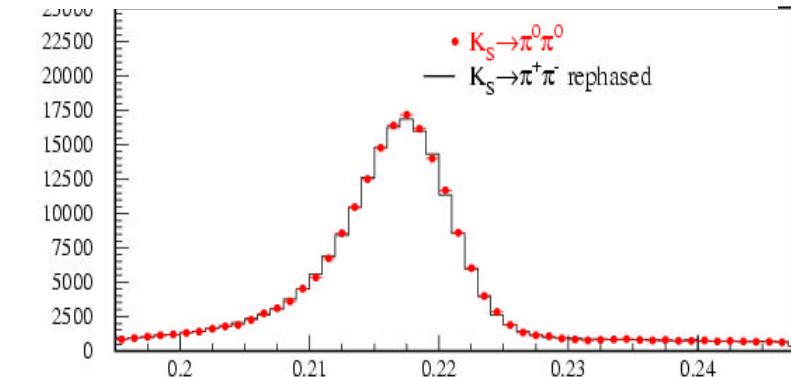
($\beta^* = K_L$ velocity in the ϕ rest frame)

$$\delta\beta = 0.004 \Rightarrow \delta W_{\text{DA}\Phi\text{NE}} = 1 \text{ MeV}$$

- ✓ relies on the measurement of \mathbf{b}^* slightly dependent on K_S decay
- ✓ easier determination of trigger efficiency
40% of times, K_L -crash triggers by itself
- ✓ K_S momentum from K_L cluster position

2000 data analysis = 5.4×10^6 K_L crash
2001 data on tape $\sim 6 \times 10^7$ K_L crash

β^* after correction for different pion velocities and trigger latency



$G(K_S \rightarrow p^+ p^- (g)) / G(K_S \rightarrow p^0 p^0)$

Motivations

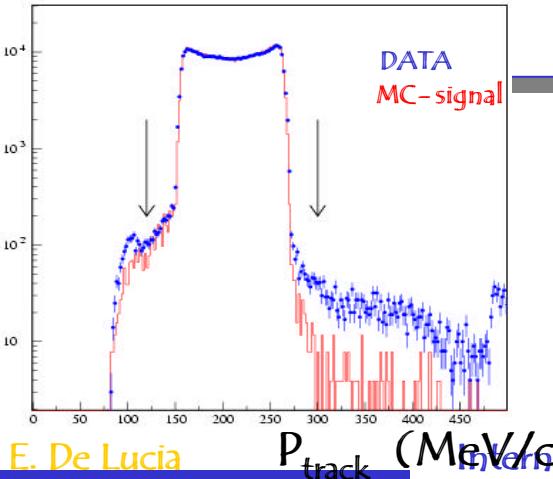
- ◊ first step towards $\text{Re}(\epsilon'/\epsilon)$
- ◊ extraction of Isospin 0 and 2 amplitudes and phases from consistent treatment of soft γ in $K_S \rightarrow \pi^+ \pi^- (\gamma)$

$K_S \rightarrow p^+ p^- (g)$ selection

- ◊ K_L -crash .and. 2 tracks from IP reaching EMC (*)
- ◊ $120 < P_{\text{track}} < 300 \text{ MeV}/c$.and. $30^\circ < \theta < 150^\circ$

fully inclusive measurement \mathbf{P} no \mathbf{g} required in EMC

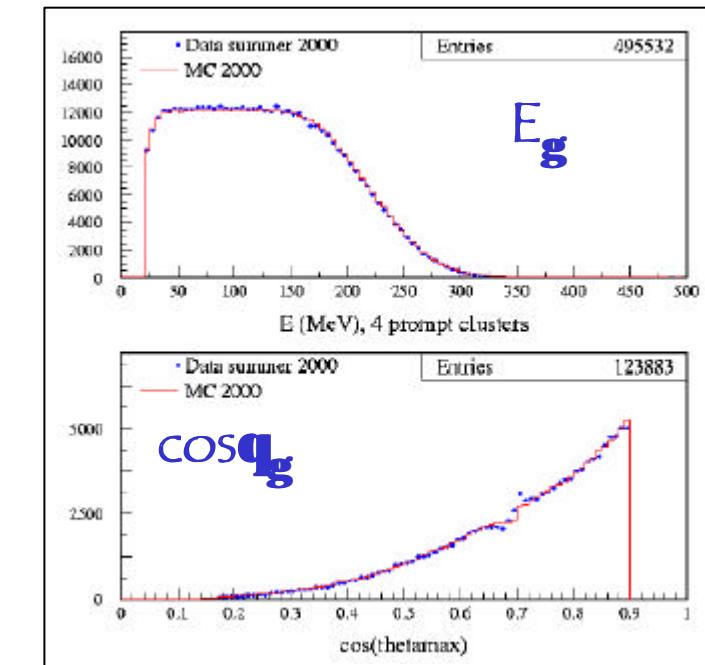
(*) acceptance depending on the photon energy E_γ^*
 $\epsilon_{\pi\pi(\gamma)}(E_\gamma^*)$ from MC folded to theoretical γ spectrum



$K_S \rightarrow p^0 p^0$ selection

- ◊ K_L -crash .and. ≥ 3 neutral "prompt" clusters: $|t^{\text{CLUS}} - R^{\text{CLUS}}|/\text{cl} < 5\sigma_t$.and.
 $E^{\text{CLUS}} > 20 \text{ MeV}$.and.
 $\cos\theta < 0.9$

acceptance and E cuts correction from MC



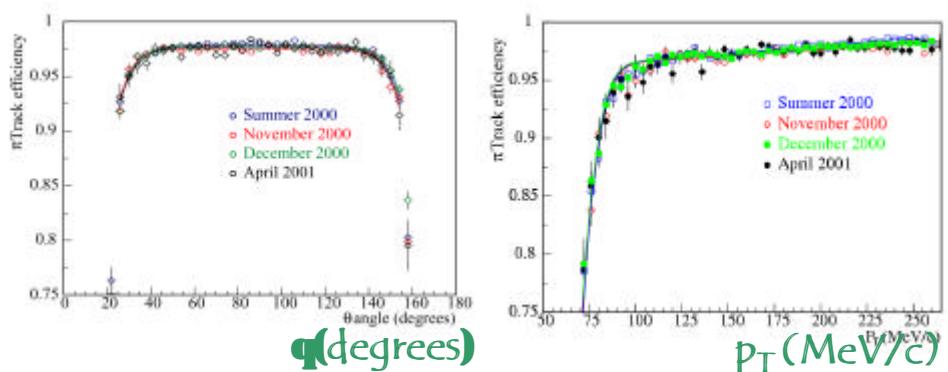


Efficiency evaluation

$K_S \rightarrow p^+ p^- (g)$

- single-track reconstruction efficiency from $K_S \rightarrow \pi^+ \pi^-$ data, used to scale MC

$$e_{+-} (\text{sel and rec}) = (57.6 \pm 0.2) \%$$



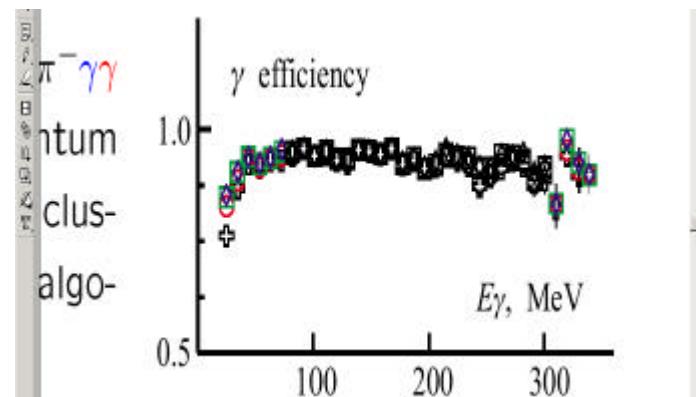
- single-particle t_0 and trigger efficiencies using data: $K_S \rightarrow p^+ p^-$ from $K_L \rightarrow p^+ p^- p^0$ -tagged sample (t_0 -independent), $f \rightarrow p^+ p^- p^0$ and $K_S \rightarrow p^+ p^-$ with 2 trigger sectors fired by K_L -crash plugged into MC

$$e_{+-} (t_0 \text{ and trig}) = (97.9 \pm 0.03) \%$$

$K_S \rightarrow p^0 p^0$

- photon detection efficiency from data using $f \rightarrow p^+ p^- p^0$ events. The overall selection efficiency (mostly acceptance):

$$e_{00} = (90.1 \pm 0.2) \%$$



- t_0 and trigger efficiency using data: $K_S \rightarrow p^0 p^0$ from $K_L \rightarrow p^+ p^- p^0$ -tagged sample (t_0 -independent), $K_S \rightarrow p^0 p^0$ with 2 trigger sectors fired by K_L -crash

$$e_{00} (t_0 \text{ and trig}) = (99.86 \pm 0.04) \%$$

$$G(K_S \rightarrow p^+ p^- (g)) / G(K_S \rightarrow p^0 p^0)$$



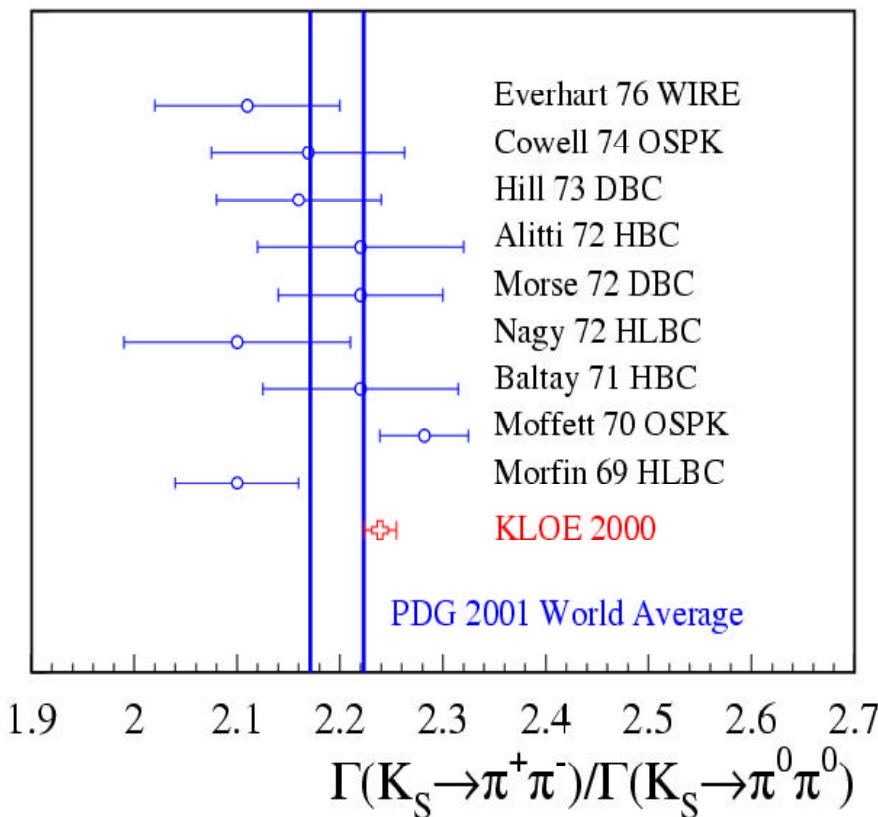
KLOE 2000 data

$2.236 \pm 0.003_{\text{stat}} \pm 0.015_{\text{syst}}$

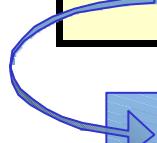
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PDG 2000 average

2.197 ± 0.026 (without clear indication of E_γ^*)



Statistical error (%)	0.14
Contribution to systematic error	%
$K_S \star \pi^0\pi^0 / K_S \star \pi^+\pi^- \text{ tag}$	0.55
photon counting	0.20
trigger and t_0	0.23
tracking	0.26
Overall systematic error	0.68



N.B. efficiencies estimated using data control samples (statistically limited)
Goal = reach 0.1% systematic uncertainty
($< 2 \cdot 10^{-4}$ on $\text{Re}(e\bar{e})$) + photon spectrum