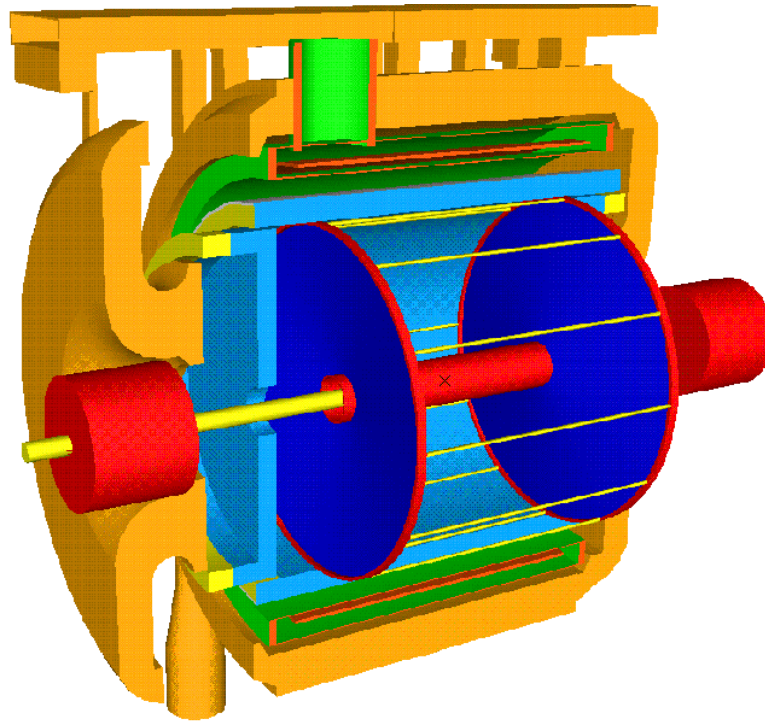




Prospects for CP -violation measurements with KLOE



T. Spadaro for the KLOE Collaboration



The KLOE Detector

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

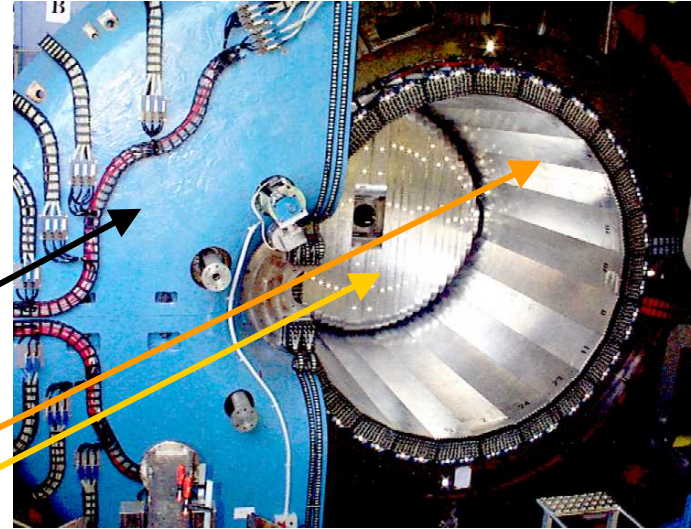
$$\sigma_t = 54 \text{ ps} / \sqrt{E(\text{GeV})} \oplus 50 \text{ ps}$$

(bunch fluctuations subtracted)

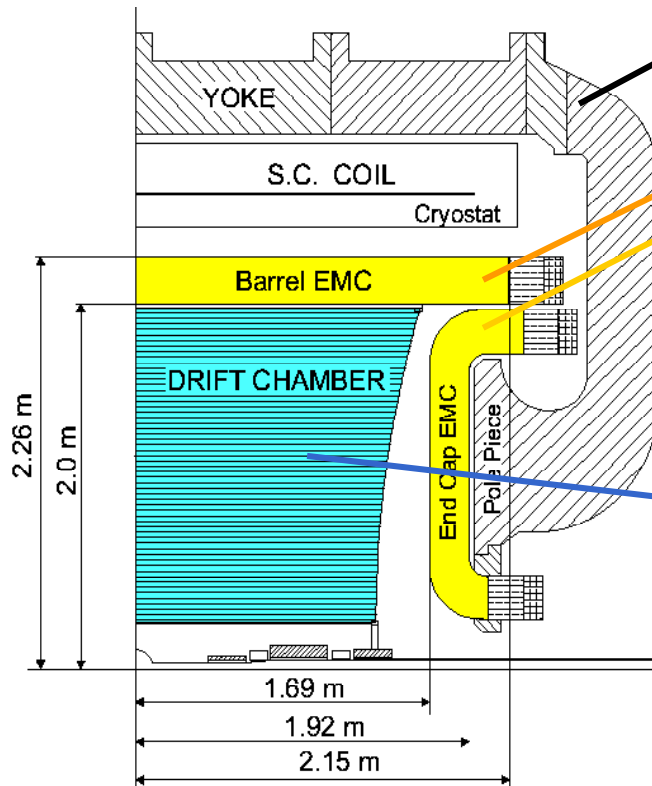
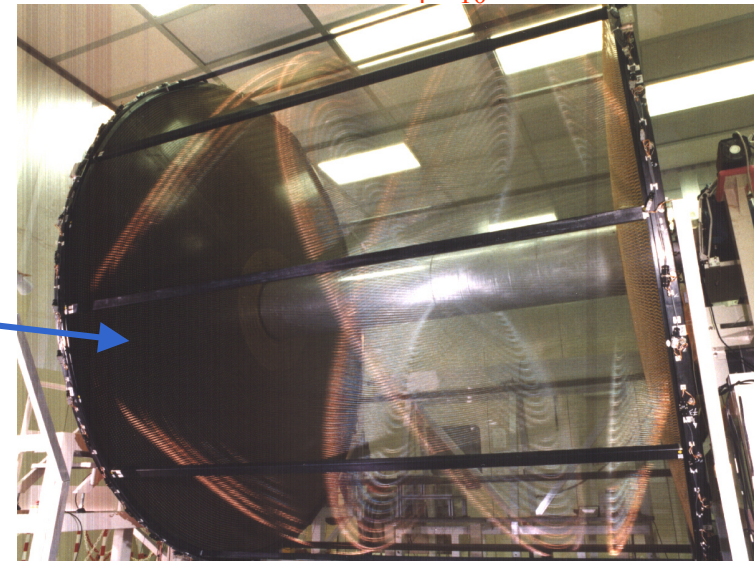
$$\sigma_p/p = 0.4 \%$$

(for 90° tracks)

Lead/Scintillating-Fiber calorimeter



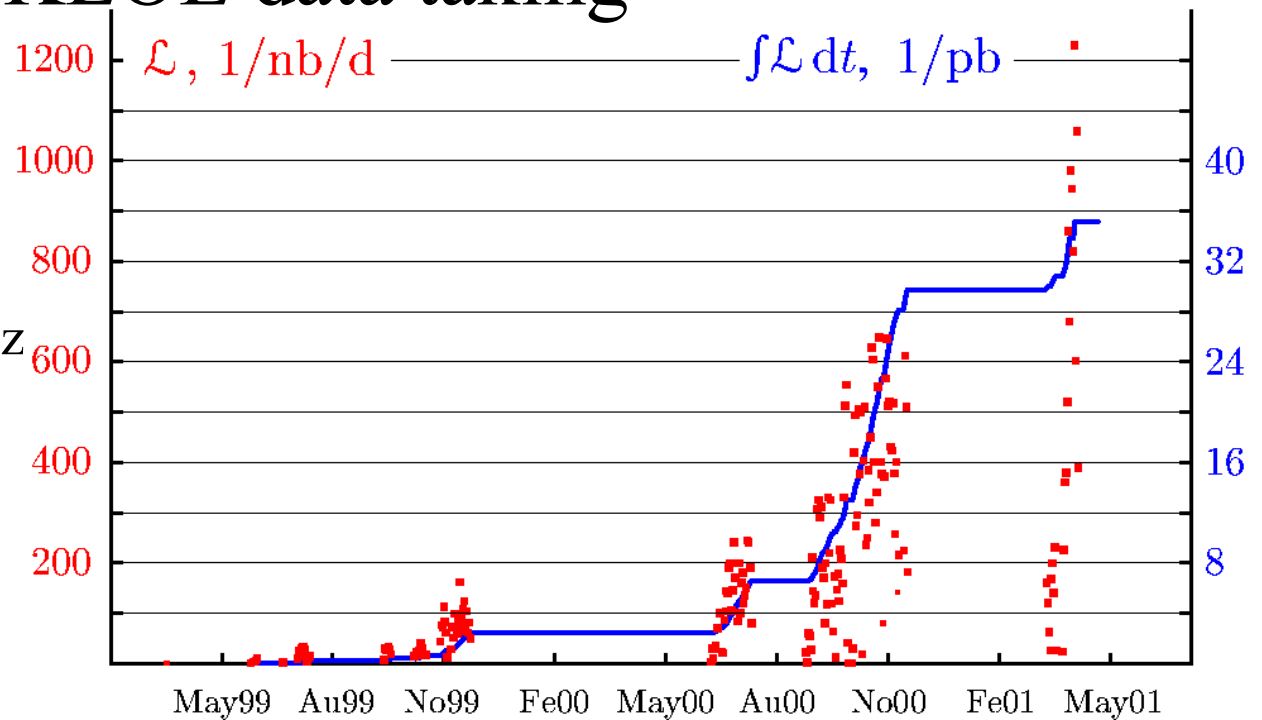
He-iC₄H₁₀ drift chamber





KLOE data taking

- $2 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ exceeded
- 1 pb^{-1} per day reached
- 35 pb^{-1} collected
- Average trigger rate 2.1 kHz



Year 2000 (23 pb^{-1})

Stream	Events (M)	Volume (GB)
$\text{K}^+ \text{K}^-$	19	687
$\text{K}_S \text{K}_L$	64	2270
$\rho \pi$	6	166
radiative	23	520
Bhabha	127	2623

10.9 M

K_L tagged by $\text{K}_S \rightarrow \pi^+ \pi^-$

7.2 M

K_S tagged by K_L interactions in EmC

Useful control samples for calibration



The KLOE Physics Program

CPT limits ($K_S \rightarrow \pi^+ e^- \nu / \pi^- e^+ \nu$ vs $K_L \rightarrow \pi^+ e^- \nu / \pi^- e^+ \nu$)

***CP* violation to several 10^{-4} (double ratio+interference)**

rare and not so rare K_S decays ($\gamma\gamma, \pi e e, \pi \mu \mu, \pi \nu \nu$)

kaon form factors ($K_L \rightarrow \pi l \nu, K^\pm \rightarrow \pi^0 l^\pm \nu$)

***CP* violation to 10^{-3} (double ratio)**

K^\pm decays (in particular $\pi^0 e^\pm \nu, \pi \pi \pi$)

σ_{HAD} for $(g-2)_\mu$ and $\alpha_{\text{em}}(m_Z^2)$ at 2%

BR of semileptonic K_S decays ($K_S \rightarrow \pi l \nu$)

regeneration measurements at low momenta

$\phi \rightarrow \pi^+ \pi^- \pi^0$

radiative ϕ decays ($\phi \rightarrow \eta \gamma, \eta' \gamma, f_0 \gamma, a_0 \gamma, \dots$)

Integrated Lum. (pb^{-1})

2000

1000

100

20

■ non Kaon physics

■ Kaon physics



Measuring ϵ'/ϵ with double ratio

$$\frac{\Gamma(K_S \rightarrow \pi^0 \pi^0)}{\Gamma(K_S \rightarrow \pi^+ \pi^-)} \bigg/ \frac{\Gamma(K_L \rightarrow \pi^0 \pi^0)}{\Gamma(K_L \rightarrow \pi^+ \pi^-)} = 1 - 6 \operatorname{Re}(\epsilon'/\epsilon)$$

$$\overset{\text{observed}}{N_{L,S}^{\pm,0}} - \overset{\text{estimated}}{Bkg_{L,S}^{\pm,0}} = \overset{\text{desired}}{N_{KK}} \times \epsilon_{L,S}(\text{tag}) \times BR_{L,S}^{\pm,0} \times \langle \epsilon_{L,S} \rangle^{\pm,0} \times \iint_{FV} \overset{g(\ell-\ell') \text{ experimental resolution}}{g(\ell-\ell')} I(\ell) d\ell d\ell'$$

$N_{KK} = \int \mathcal{L} dt \cdot \sigma_\phi \cdot BR(\phi \rightarrow K^0 \bar{K}^0)$
drops out identically

$\epsilon_{L,S}(\text{tag})$ almost cancel out

$I(\ell)$ decay intensity
 $K_L \rightarrow \pi^+ \pi^- \pi^0$ and
 K_S regeneration at DC wall
 can also be used to align FV's

- K_S beam: tagged by K_L interactions in the calorimeter
- K_L beam: tagged by $K_S \rightarrow \pi^+ \pi^-$ reconstruction

With tagged beams at KLOE one can also measure absolute BR's



$K_S \rightarrow \pi^+ \pi^- / K_S \rightarrow \pi^0 \pi^0$: tagging

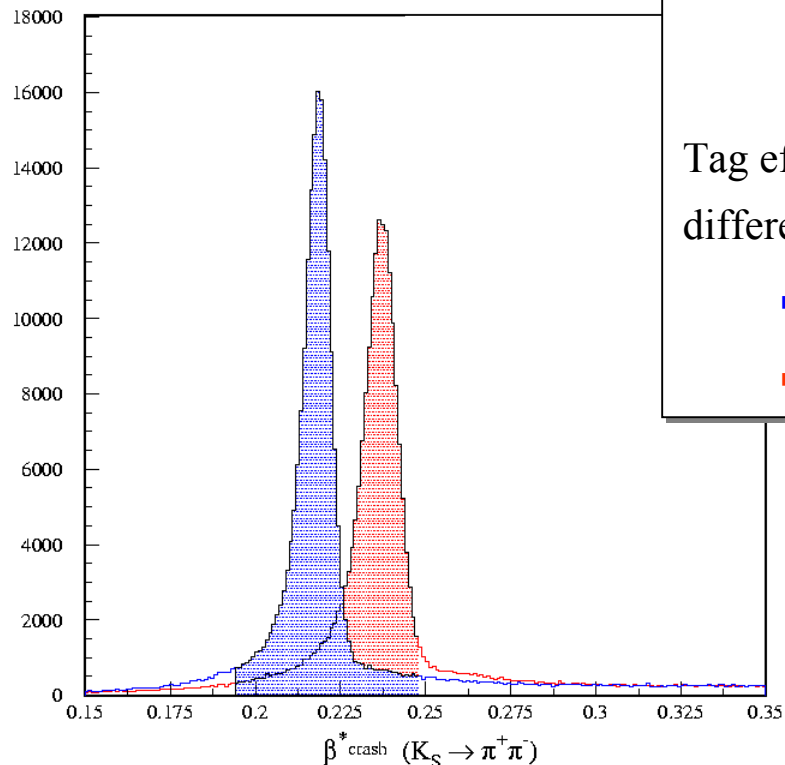
Clean K_S selection by time-of-flight of K_L interacting in the EmC
(β^* = K_L velocity in the center of mass system)

Selection cuts:

- $E_{\text{clus}} \geq 100 \text{ MeV}$
- $|\cos(\theta_{\text{clus}})| \leq 0.7$
- $\beta^* \in [0.195, 0.2475]$

Tag efficiency is slightly dependent on the channel due to the different timing of the events (global t_0) given by:

- prompt γ 's in $\pi^0 \pi^0$
- pion clusters in $\pi^+ \pi^-$



$$\epsilon^{+-} / \epsilon^{00} = (95.03 \pm 0.005) \%$$

Ratio of tag efficiencies is estimated directly from data



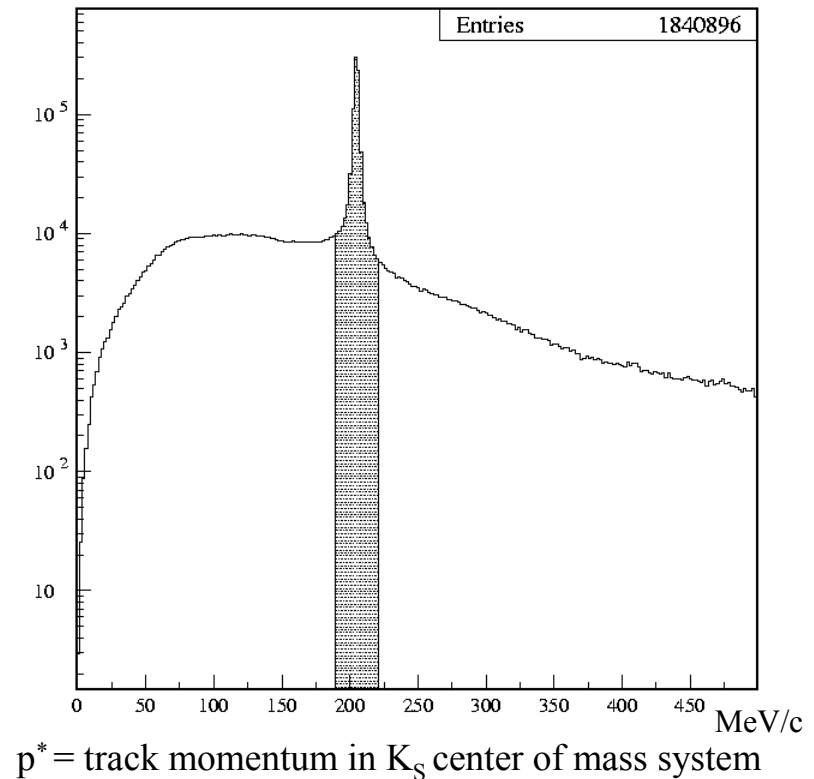
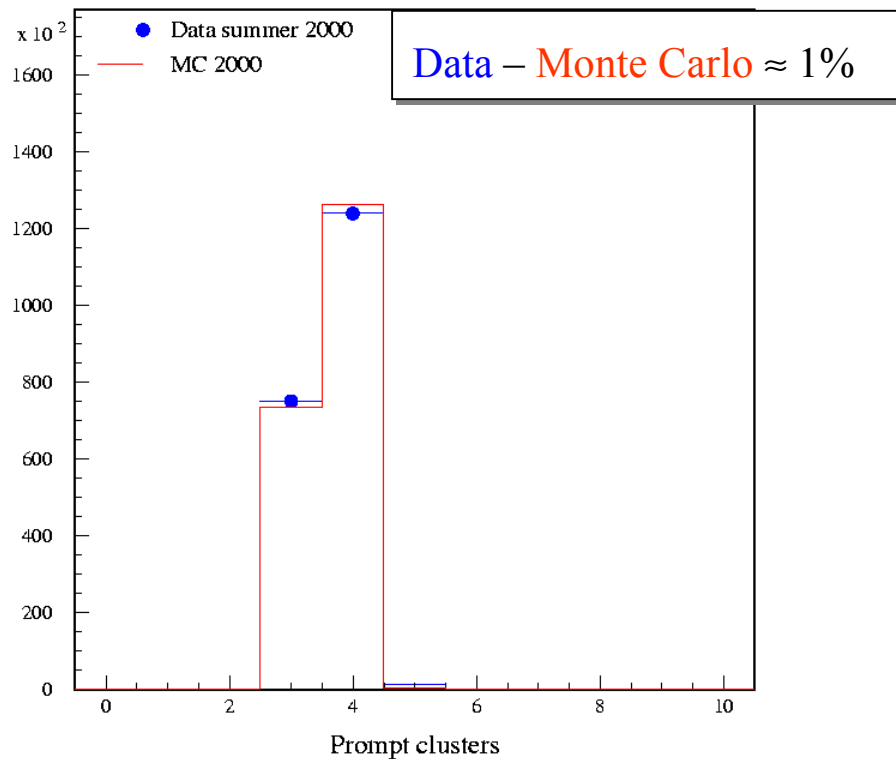
$K_S \rightarrow \pi^+ \pi^- / K_S \rightarrow \pi^0 \pi^0$: signal selection

$\pi^0 \pi^0$: 4 prompt clusters required

- $|t - R/c| \leq \min(5 \sigma_t ; 3 \text{ ns})$
- $\cos \theta < 0.9$
- $E > 20 \text{ MeV}$

$\pi^+ \pi^-$: 2 opposite charged tracks required

- tracks from IP ($|z| \leq 10 \text{ cm}$; $\rho \leq 4 \text{ cm}$)
- $\cos \theta < 0.9$
- $190 < p^* < 220 \text{ MeV/c}$





$K_S \rightarrow \pi^+ \pi^- / K_S \rightarrow \pi^0 \pi^0$: results

PDG 2000 $R = 2.197 [1 \pm 1.2 \times 10^{-2} \text{ (stat)} \pm 0.6 \times 10^{-2} \text{ (syst)}]$

KLOE 1999 $R = 2.237 [1 \pm 4 \times 10^{-3} \text{ (stat)} \pm 7 \times 10^{-3} \text{ (syst)}]$

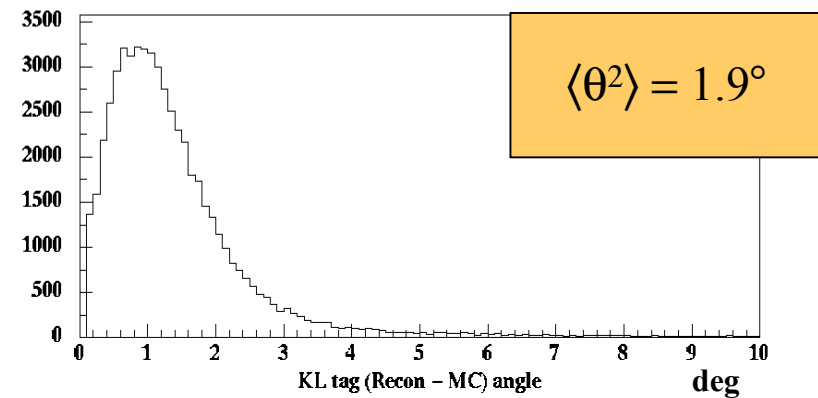
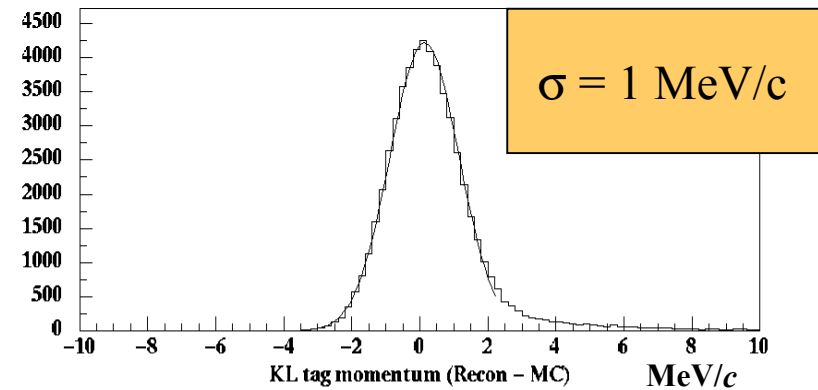
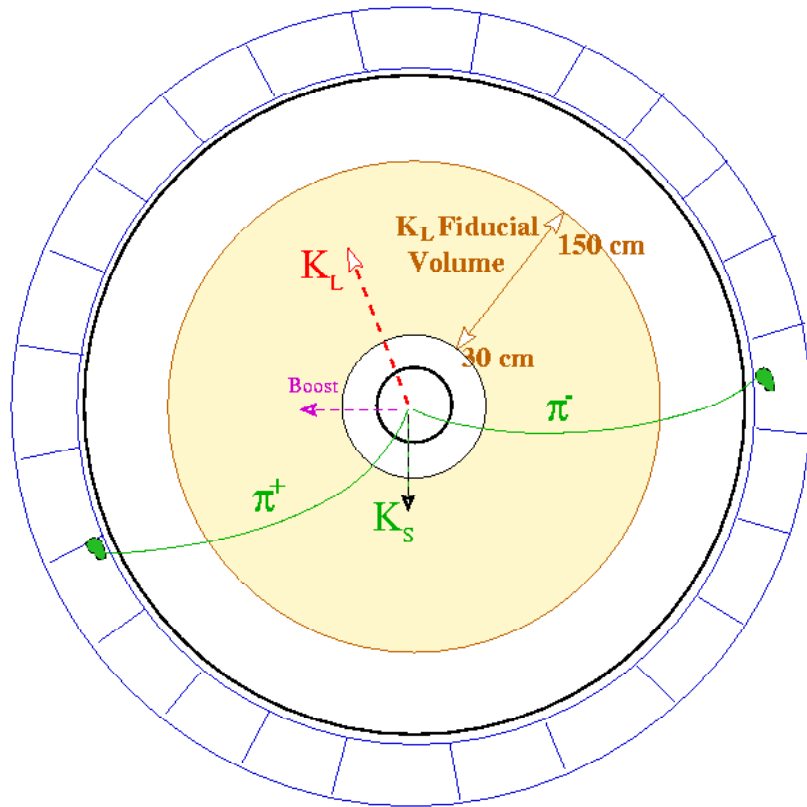
KLOE 2000 $R = 2.16 [1 \pm 3.6 \times 10^{-3} \text{ (stat)}]$ *preliminary (15% of statistics)*

Systematics is under study on 2000 data:

tag efficiency	$\pi^0 \pi^0 / \pi^+ \pi^- \beta^*$ spectra
cluster counting	DATA/MC comparison + accidentals
track efficiency	DATA/MC comparison + spurious hits
t_0 and trigger efficiency	extract efficiencies directly from DATA



K_L tag using $K_S \rightarrow \pi^+\pi^-$ vertex



K_L tagged by K_S vertex, e.g. ($\epsilon = 73\%$):

$$r_{xy} < 5 \text{ cm}, |z| < 20 \text{ cm}$$

$$|M - M_{KS}| < 20 \text{ MeV}/c^2$$

Search for $K_L \rightarrow \pi^+\pi^-$ in 6° cone about $(\mathbf{p}_{\text{boost}} - \mathbf{p}_{KS})$



$K_L \rightarrow \pi^+\pi^-$: Event selection

Fiducial volume ($\epsilon = 26\%$):

$$35 < r_{xy} < 150 \text{ cm}$$

$$|z| < \sim 120 \text{ cm}$$

+ Data (5 pb^{-1})

— MC signal

— MC background

K_L vertex reconstructed in FV ($\epsilon = 75\%$)

K_L identification ($\epsilon = 76\%$):

Preselection:

$$P_{\text{miss}}^2 + E_{\text{miss}}^2 < (30 \text{ MeV})^2$$

Additional rejection from simple kinematic fit:

Variable parameters:

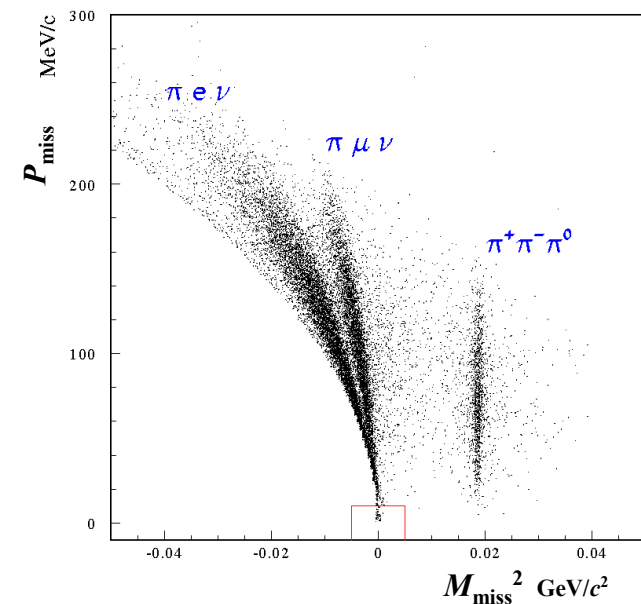
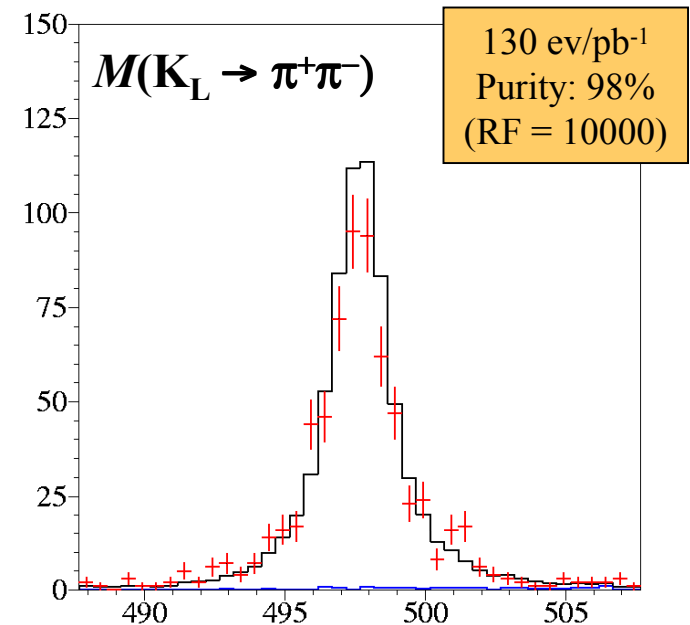
Scale factors for p_π (f_{KS}, f_{KL})

Opening angles (θ_{KS}, θ_{KL})

Constraints:

M_{KS}, M_{KL} , conservation of total E, \mathbf{p}

Good efficiency and high purity not a problem





$K_L \rightarrow \pi^+\pi^-$: Systematic studies

- Effort to measure efficiency and background directly from data
- Event symmetry allows use of **double tag method**

Decay tag:

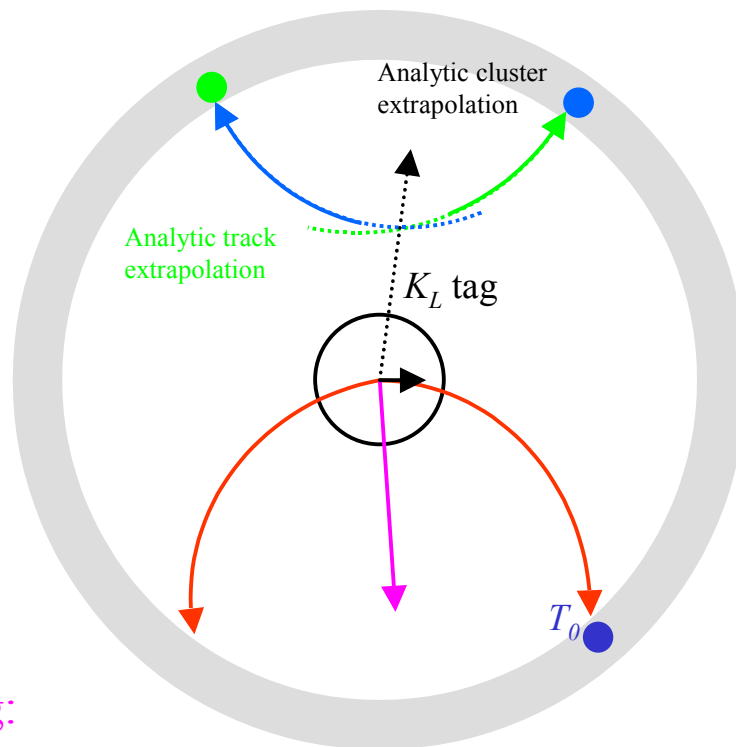
1 track + p^* compatible with signal + opposite cluster

$$N_1 = 2\varepsilon S + B_1$$

$$N_2 = \varepsilon^2(1-\rho)S + B_2$$

$$S = 4(1-\rho)N_1^2/N_2$$

$$\varepsilon = 2N_2/[N_1(1-\rho)]$$



Event tag:

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

Preliminary results:

$$N_1 - B_1 = 3658 \pm 123$$

$$B_1 = 3277 \pm 65$$

$$N_2 - B_2 = 996 \pm 34$$

$$B_2 = 29 \pm 3$$

$$S = 4226 \pm 287$$

$$\varepsilon = 0.433 \pm 0.019$$

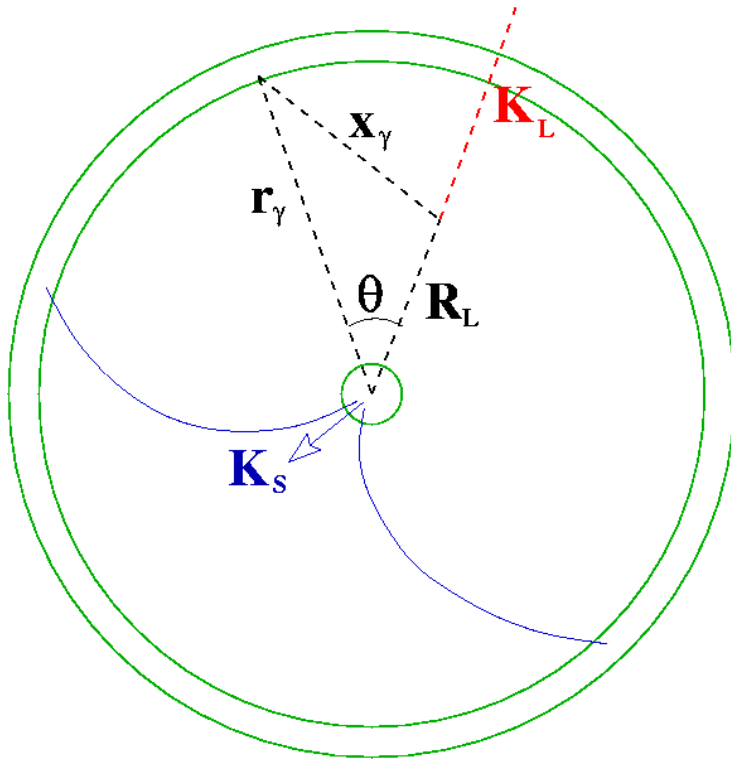
ε extracted from data + some MC input



$K_L \rightarrow \pi^0 \pi^0$ vertex reconstruction

The K_L decay vertex position is determined by measuring:

1. the K_L flight direction (from $K_S \rightarrow \pi^+ \pi^-$ momentum balance),
2. the photon conversion point (r_γ)
3. the time of flight of the K_L and of the photon(s) ($R_L/\beta_L + x_\gamma/c$)



$$\begin{cases} x_\gamma^2 = r_\gamma^2 + R_L^2 - 2r_\gamma R_L \cos \vartheta \\ ct = R_L / \beta_L + x_\gamma \end{cases}$$

- 4 γ neutral vertices are considered for signal selection

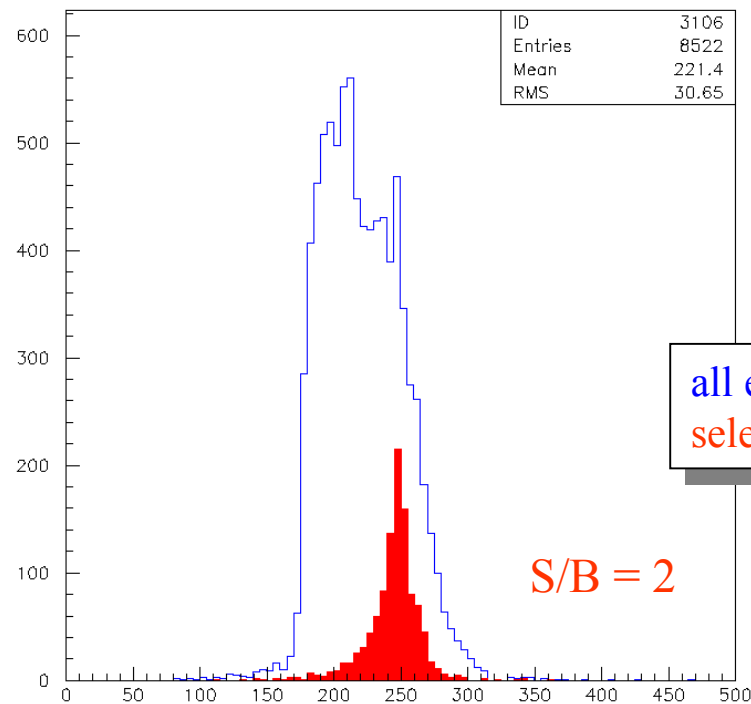


$K_L \rightarrow \pi^0 \pi^0$ selection criteria

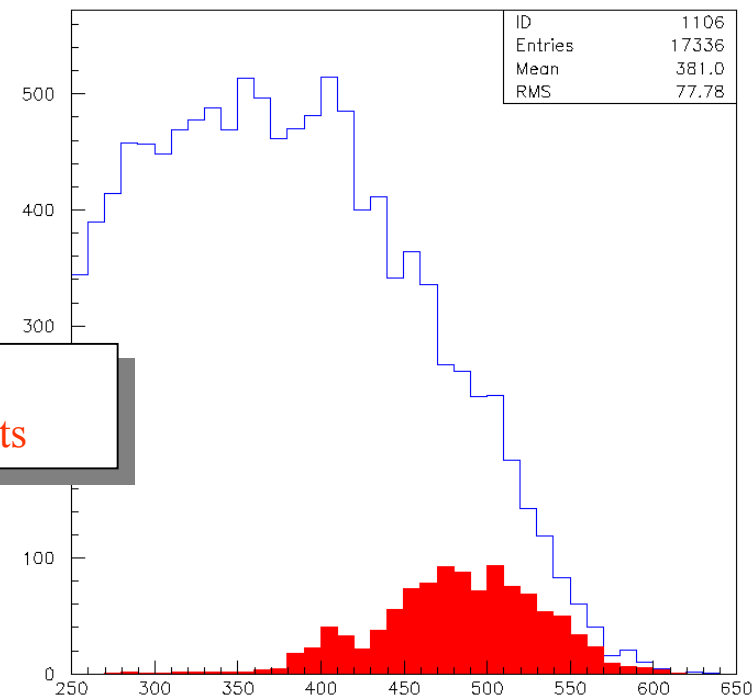
Events with 4 photons connected to the neutral vertex in fiducial volume

1. 4-momentum conservation at the neutral vertex
2. $\gamma\gamma$ pairings and π^0 reconstruction: $M(\pi^0)$ vs. $E(\pi^0)$ in K_L rest frame

Global fit uses both types of information.



π^0 energy in K_L rest frame



K_L invariant mass

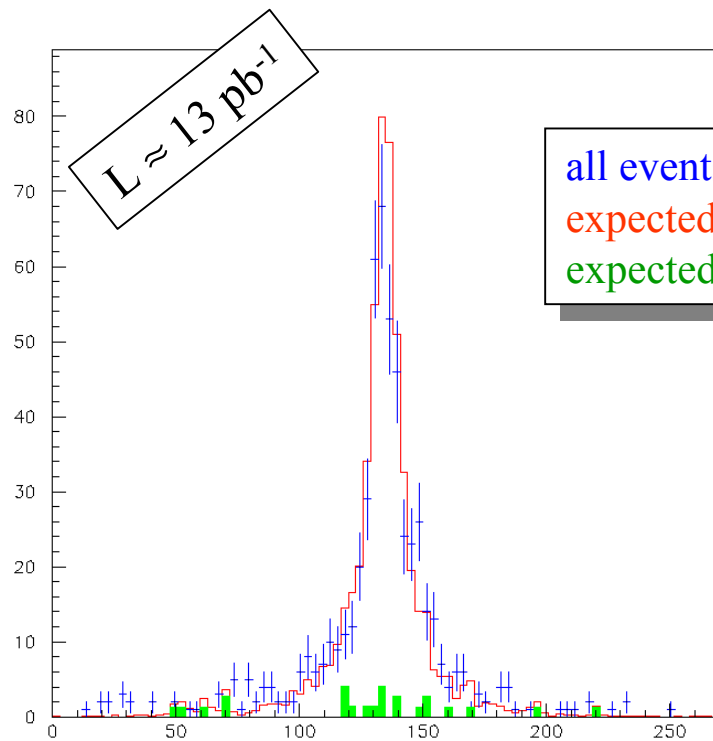


$K_L \rightarrow \pi^0 \pi^0$ signal (hard selection)

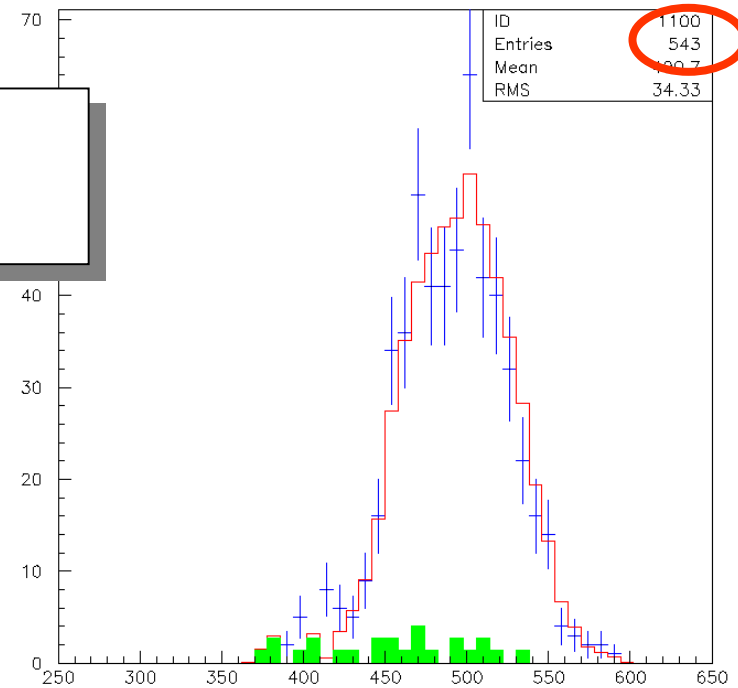
All events with 4 γ in the FV :

- $|z| < 155$ cm
- $30 < r < 155$ cm
- 4-momentum conservation
- 2 π^0 reconstructed

- $S/B = 17$
- Yield = 40 events/ pb^{-1}
- Consistent with expectation for $\text{BR}(K_L \rightarrow \pi^0 \pi^0) / \text{BR}(K_L \rightarrow \pi^0 \pi^0 \pi^0)$ within current statistics



π^0 mass



K_L invariant mass



Conclusions

- KLOE has collected 35 pb⁻¹ to date...
- A competitive measurement of $\text{BR}(\text{K}_S \rightarrow \pi^+ \pi^-) / \text{BR}(\text{K}_S \rightarrow \pi^0 \pi^0)$ has been obtained
- Two techniques for measuring $\text{BR}(\text{K}_L \rightarrow \pi^+ \pi^-)$ have been developed; reconstruction and selection efficiencies are under detailed study
- $\text{K}_L \rightarrow \pi^0 \pi^0$ selection algorithm has been developed; efficiency has to be determined from data
- Work on agreement between data and Monte Carlo is underway
- ...200 pb⁻¹ will be collected by the end of 2001:
this kind of statistics will allow us to attack the ϵ'/ϵ measurement