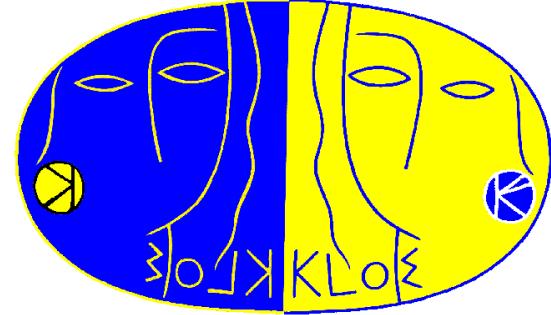


# Status report on kaon physics of the KLOE experiment

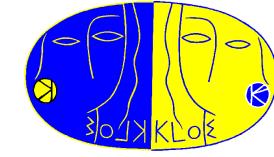
---



**M. Martemianov**

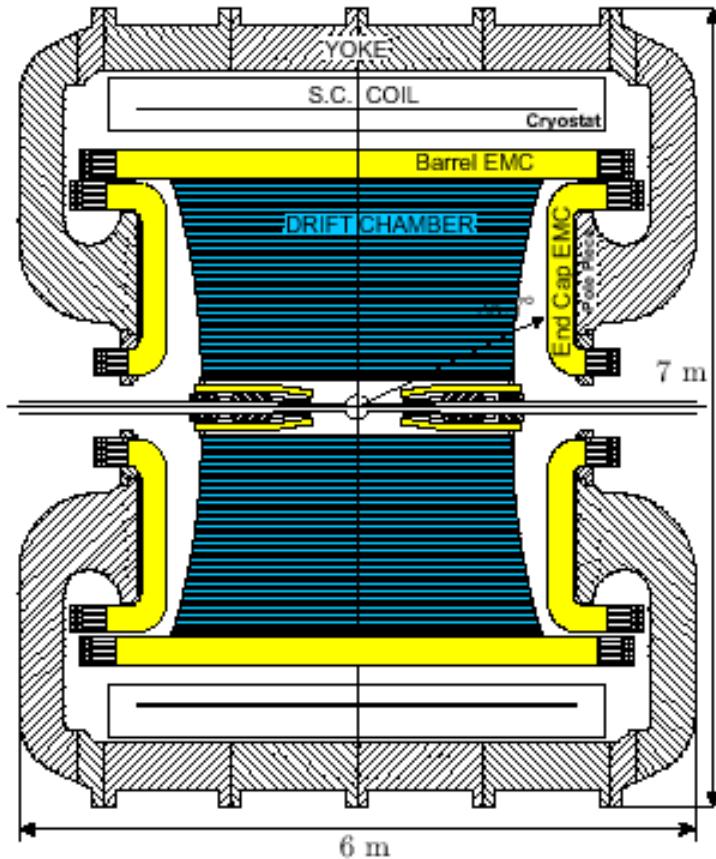
**INFN - Laboratori Nazionali di  
Frascati**

10th Lomonosov Conferences on Elementary Particle Physics,  
Moscow State University,  
Moscow, Russia, 23-29 August, 2001

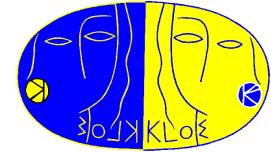


# Outline

---



- Physics at  $\phi$  - factory
- KLOE detector and DAFNE factory in Laboratori Nazionali di Frascati (LNF)
- KLOE physics program
- $K^+ K^-$  physics : preliminary results
- Conclusion



# Physics at $\phi$ - factory

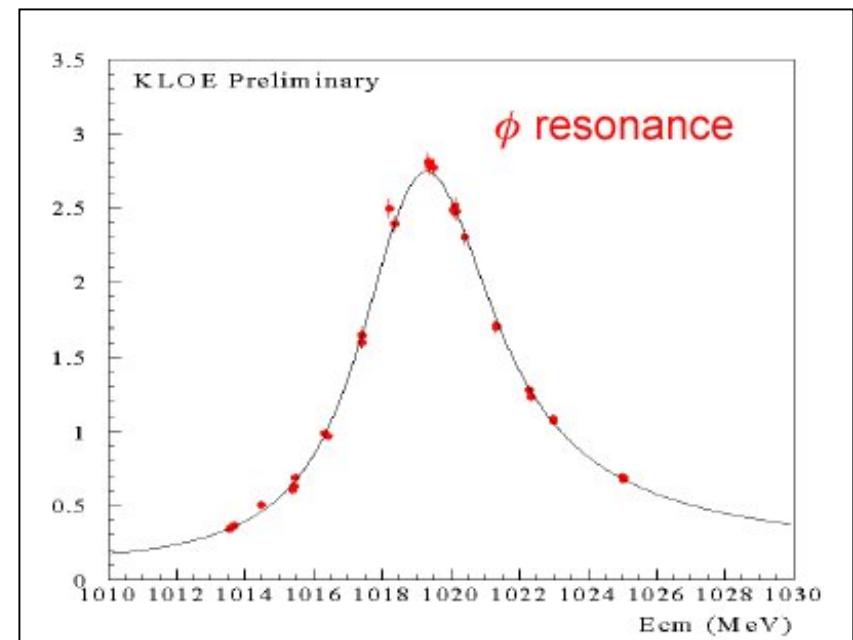
- $e^+e^-$  collider at  $\phi$  - peak

Main  $\phi$  - parameters :

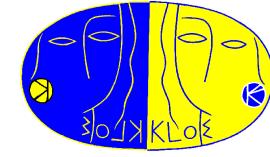
$$\sigma(e^+e^- \rightarrow \phi) \approx 3.2 \text{ } \mu\text{b}$$

$$M_\phi = 1020 \text{ MeV}$$

$$\Gamma_\phi = 4.4 \text{ MeV}$$



- Very clean hadronic environment
- $K_S K_L$  beams in pure quantum state ( $J^{PC} = 1^{--}$ )



# Physics at $\phi$ - factory

Decay length :

$$\lambda(K^+K^-) = 95 \text{ cm}$$
$$(\tau = 12.4 \text{ ns})$$

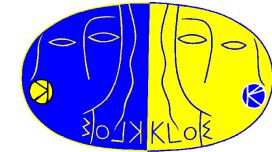
$$\lambda(K_S) = 0.6 \text{ cm}$$
$$(\tau = 90.0 \text{ ps})$$

$$\lambda(K_L) = 343 \text{ cm}$$
$$(\tau = 51.7 \text{ ns})$$

BR for selected  $\phi$  decays

$K^+K^-$	49.1%
$K_SK_L$	34.1%
$\rho\pi, \pi^+\pi^-\pi^0$	15.5%
$\eta\gamma$	1.3%
$f_0\gamma, a_0\gamma, \eta'\gamma$	$\sim 10^{-4}$

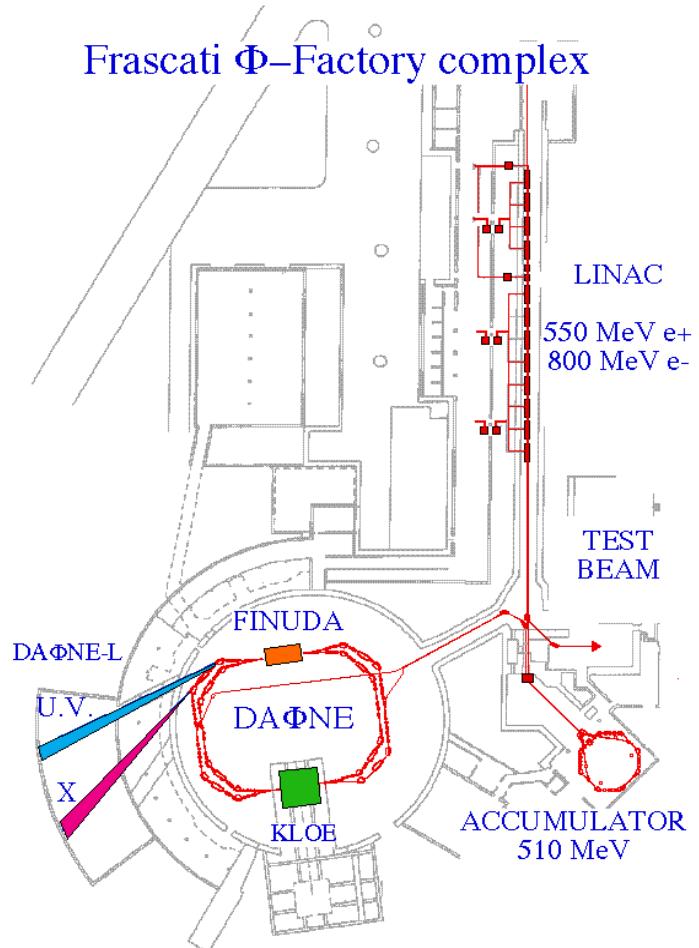
Pure and monochromatic kaons beam,  
 $P_k \approx 110 \text{ MeV/c}$

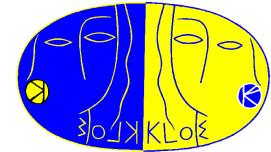


# DAPHNE $\phi$ - factory

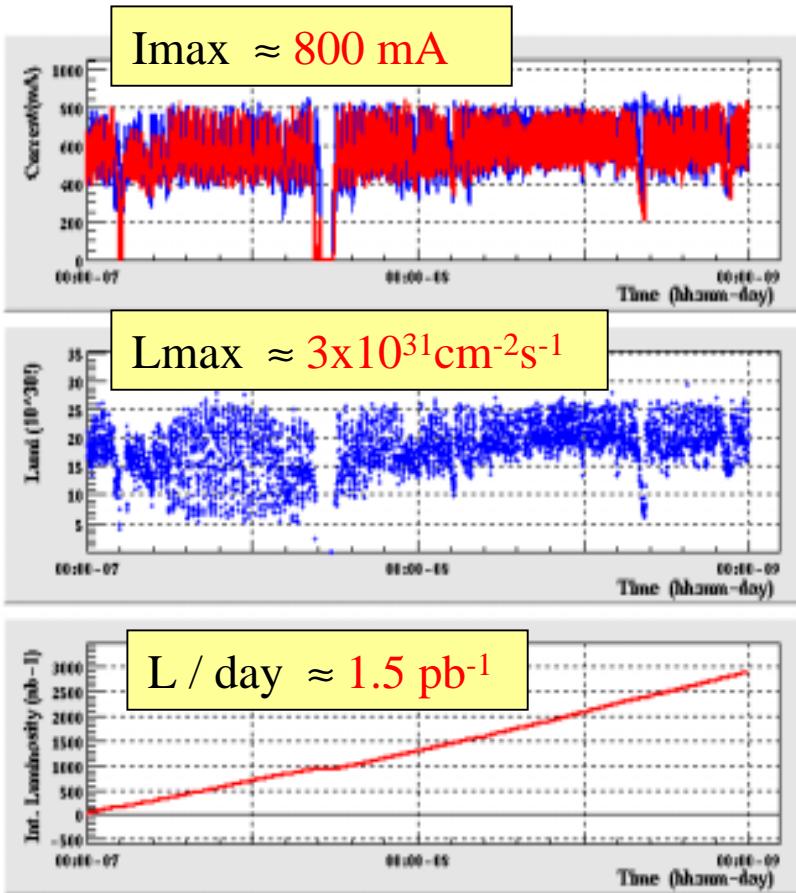
## Design parameters

• Trajectory (m)	98
• Beam energy (MeV)	510
• Max number of bunches	120
• Bunch spacing (ns)	2.7
• Bunch current (mA)	40
• Bunch size horiz/vert ( $\mu\text{m}$ )	2000/20
• Crossing angle (mrad)	25
• Bunch luminosity ( $\text{cm}^{-2}\text{s}^{-1}$ )	$4 \times 10^{30}$
• Total luminosity ( $\text{cm}^{-2}\text{s}^{-1}$ )	$5 \times 10^{32}$

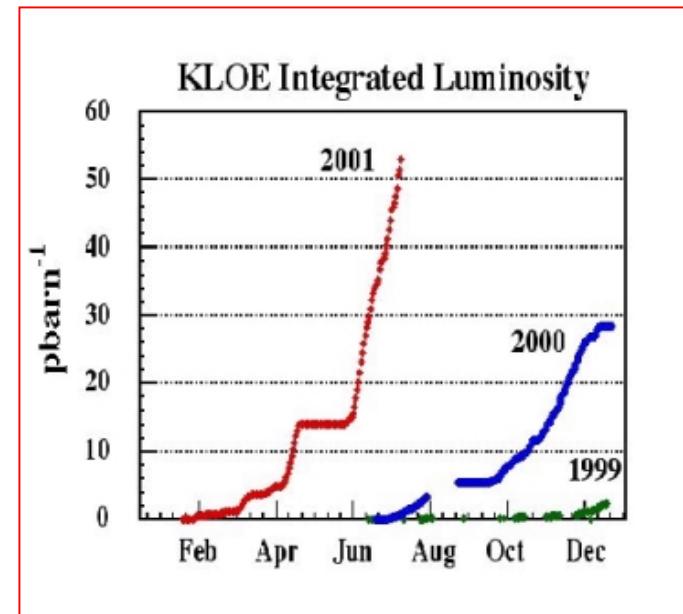




# DAFNE present parameters

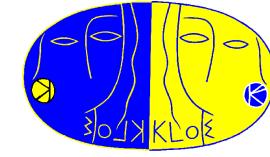


$L_{max}$  for VEPP2M  $\approx 5 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1}$

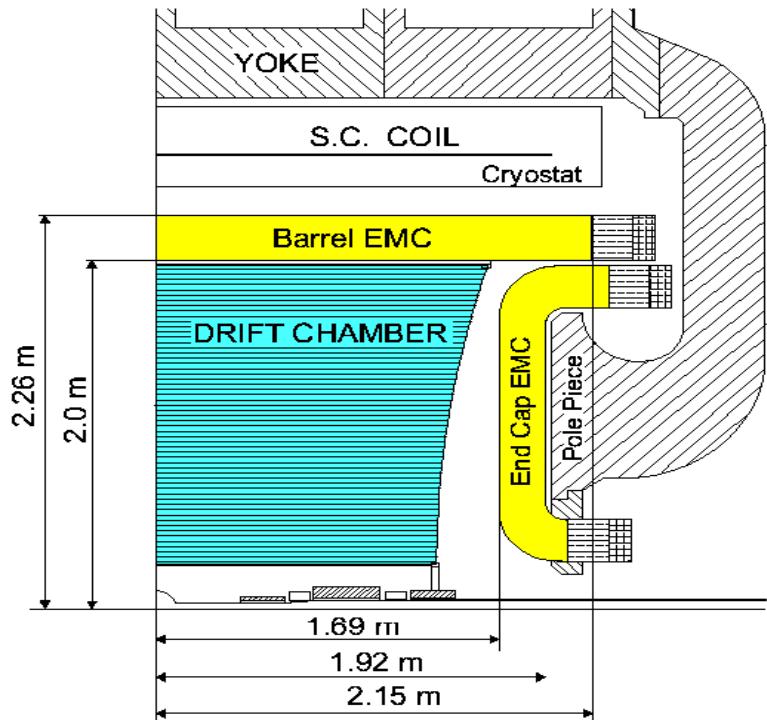


Total integrated luminosity  
1999-2001 year :  $L \approx 80 \text{ pb}^{-1}$

(CMD2 on VEPP2M for all  
its life time  $\approx 14.3 \text{ pb}^{-1}$ )



# KLOE detector



Total weight of detector  $\approx$  1000 tons

## Electromagnetic Calorimeter (EMC)

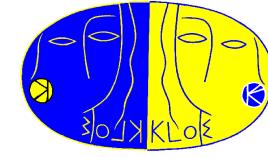
- Lead/Scintillating - Fiber calorimeter
- 24 Barrel Modules
- 64 End-Cap Modules
- 4880 channels

## Drift Chamber (DC)

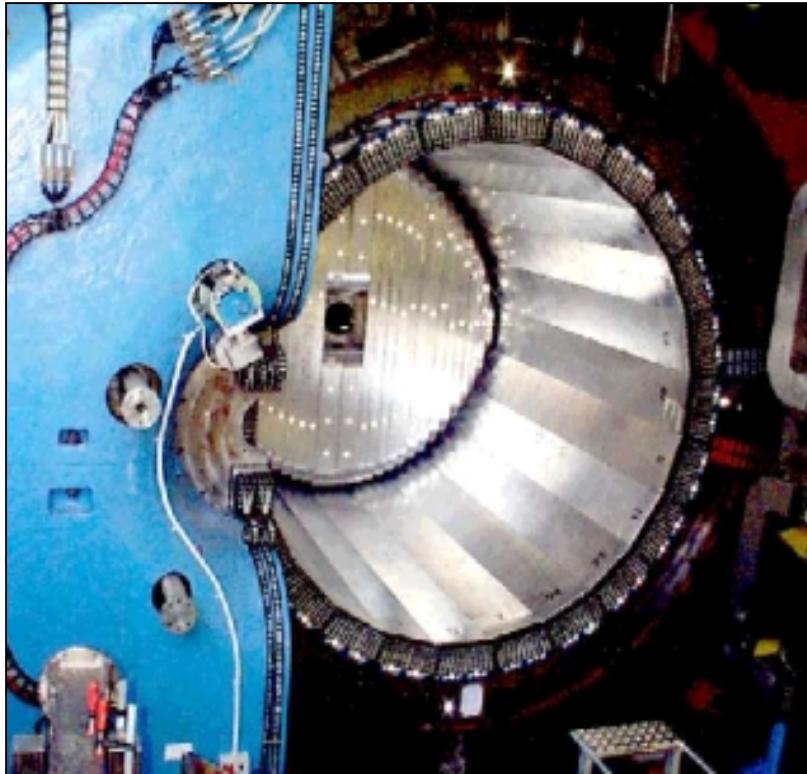
- Cylindrical structure, (4 m  $\varnothing \times$  3.3 m)
- 12582/52140 sense/total wires
- All stereo geometry
- Helium (90 %) + Isobutan gas mixture (10 %)

## Quadrupole Calorimeter (QCAL)

- Lead/Scintillator tile calorimeter inside KLOE

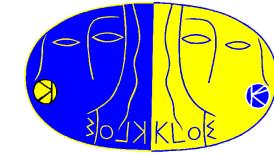


# Electromagnetic calorimeter

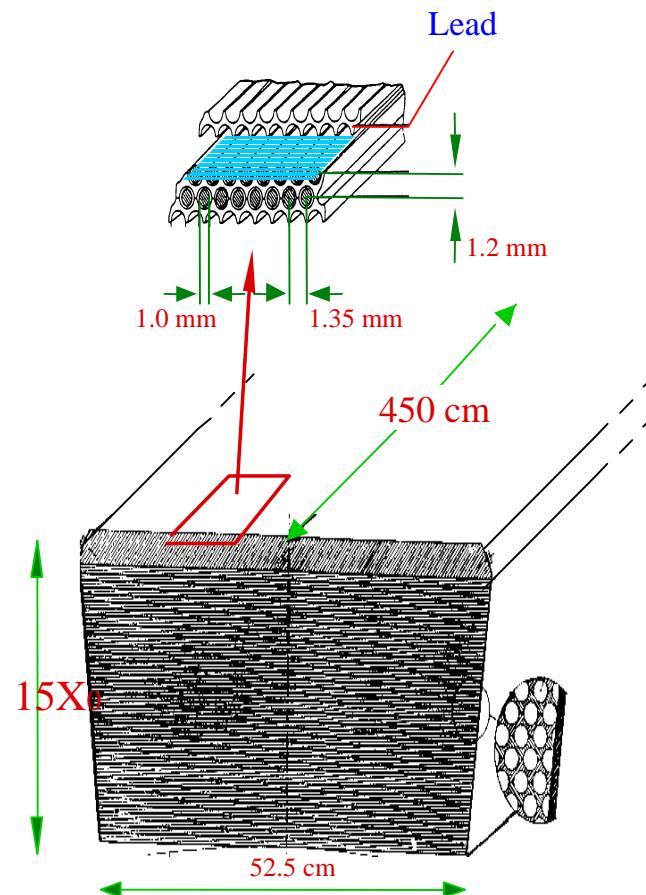


## EMC parameters

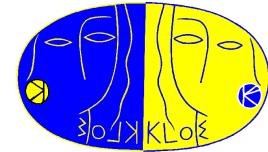
- Hermetical coverage
- Total weight  $\approx 100$  tons
- High efficiency for low energy photons
- Energy range  
 $20 \text{ MeV} < E_\gamma < 300 \text{ MeV}$
- Energy resolution  
 $\sigma_E/E = 5.7 \% / \sqrt{E} \text{ (GeV)}$
- Time resolution  
 $\sigma_t = 50 \text{ ps} / \sqrt{E} \text{ (GeV)}$



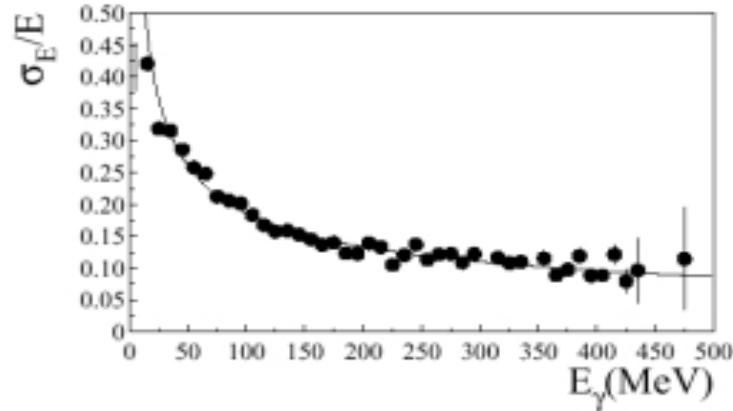
# Electromagnetic calorimeter



- Fine sampling lead / scintillating fiber calorimeter
- 1 mm fibers + 0.5 mm lead foils
- Energy sampling fraction: 13 %
- $\rho = 5 \text{ g/cm}^3 \quad X_0 = 1.6 \text{ cm}$
- 23 cm thick :  $15 X_0$
- Spatial resolution  $\sim 1 \text{ cm}$
- Both sides readout to obtain Z coordinate

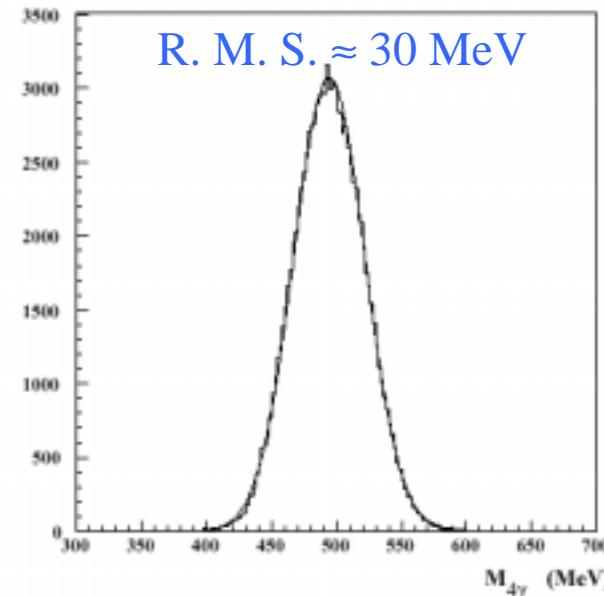


# EMC energy resolution

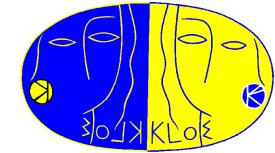


Energy resolution vs.  $E\gamma$  (MeV) for  
 $e^+e^- \gamma$  events. Fit gives :

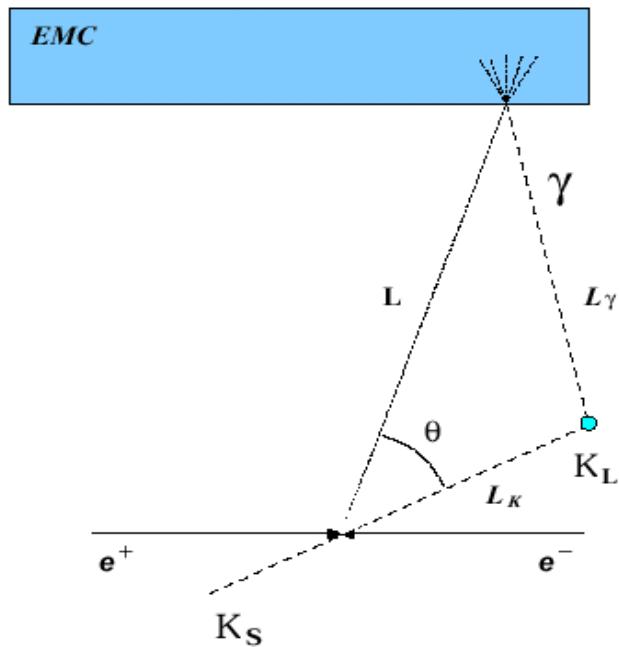
$$\sigma_E/E = 5.7 \% / \sqrt{E} \text{ (GeV)}$$



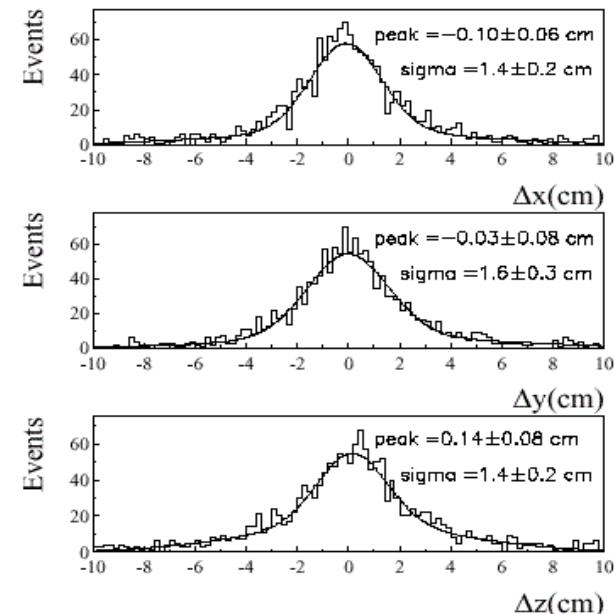
Ks mass from photon energies  
in  $Ks \rightarrow \pi^0\pi^0$



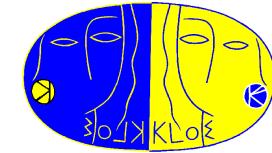
# EMC spatial resolution



Determination of **K<sub>L</sub>** path based on the measurement of time and position of one photon



Difference between x, y, and z of the  $K_L \rightarrow \pi^+ \pi^- \pi^0$  decay point from tracking and calorimeter

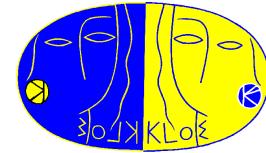


# Drift chamber

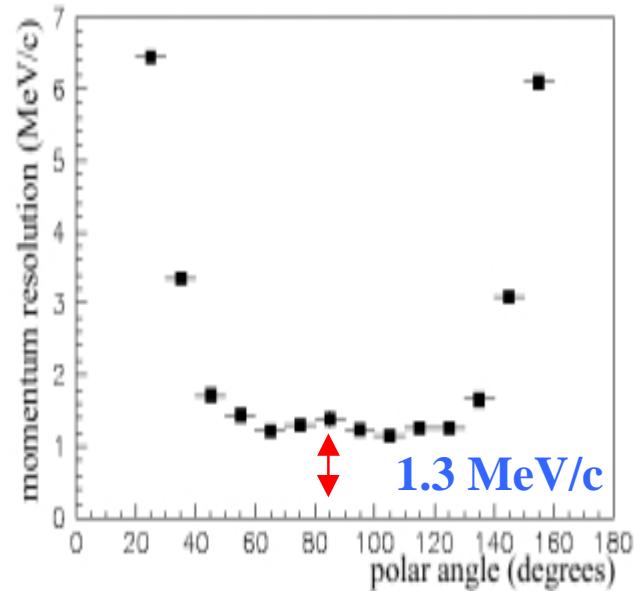
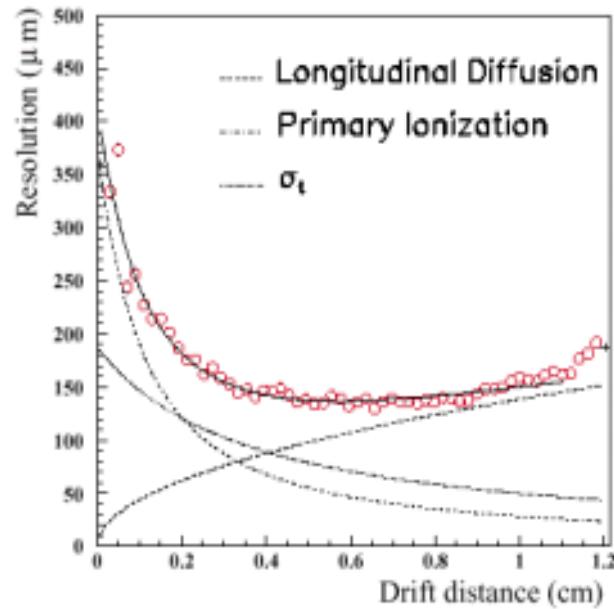


## DC parameters

- Cell geometry :
  - 12 inner layers  $2 \times 2 \text{ cm}^2$
  - 46 outer layers  $3 \times 3 \text{ cm}^2$
- Stereo angle  $\pm(60 \div 150) \text{ mrad}$
- Total tension  $\approx 2 \text{ tonn}$
- Rad. length  $X_0(\text{DC})$  900 m
- Space resolution :
$$\sigma_{r,\phi} = 200 \text{ } \mu\text{m} \text{ and } \sigma_z = 2 \text{ mm}$$

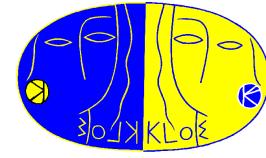


# DC resolution

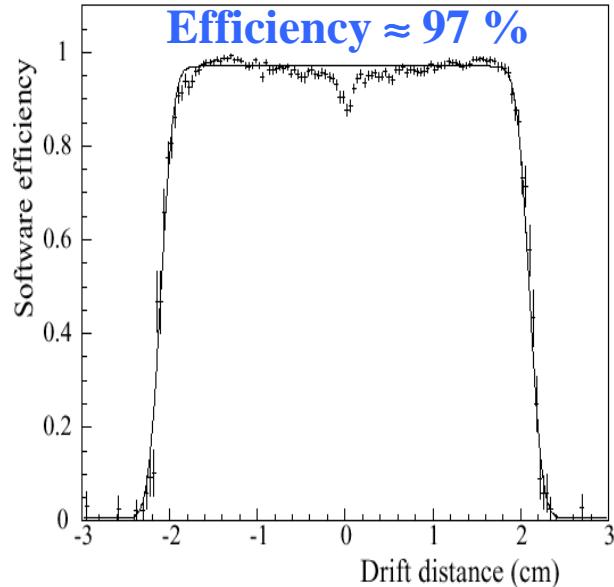


Average spatial resolution for big cells

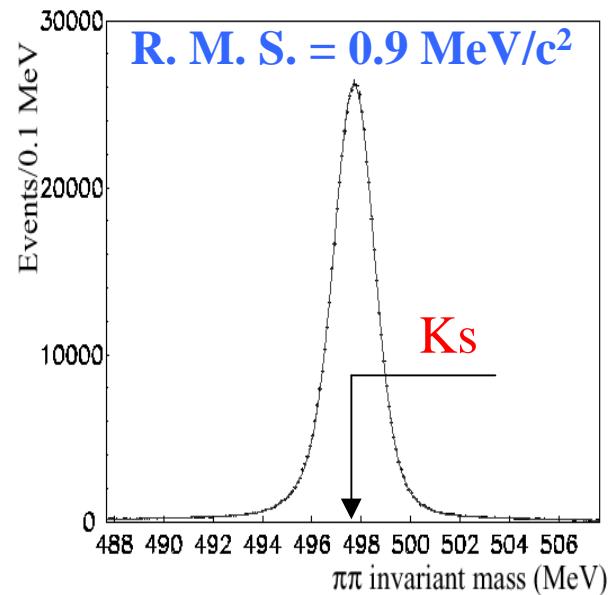
Momentum resolution for electrons and positrons of 510 MeV/c



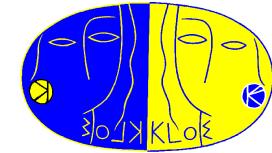
# DC cell efficiency



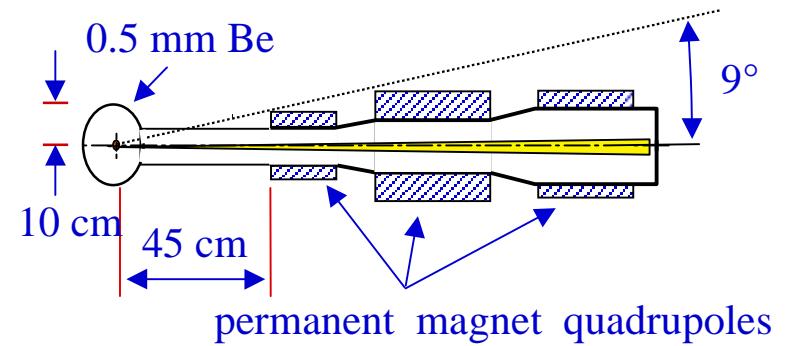
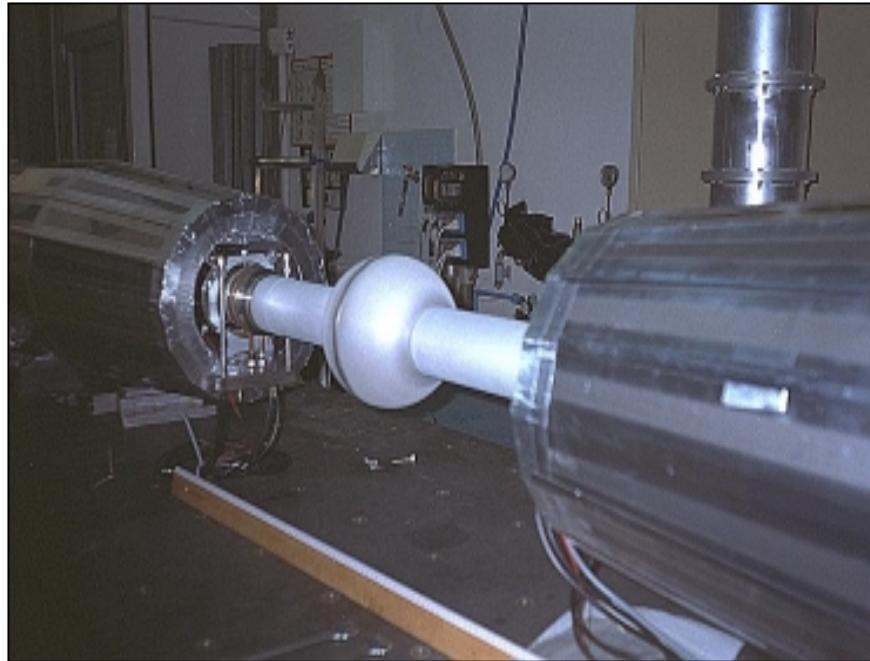
**Software efficiency as a function of drift distance**



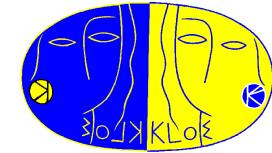
**$\pi^+ \pi^-$  invariant mass with two unlike sign tracks**



# QCAL and beam pipe

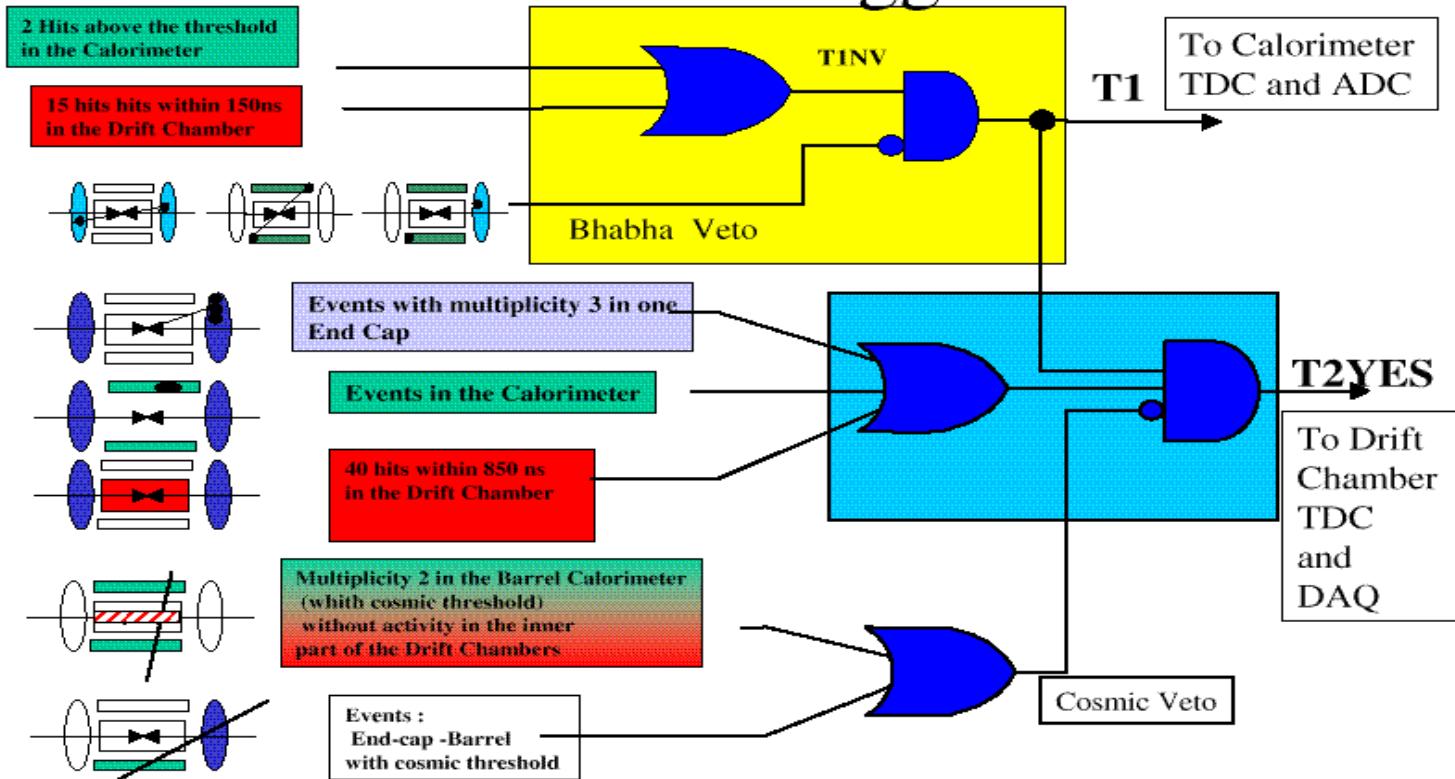


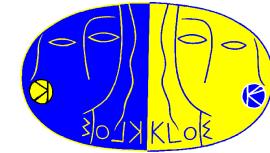
- Be walls minimize regeneration, multiple scattering, and energy loss
- Quadrupoles improves the rejection of  $K_L \rightarrow 3\pi^0$  by a factor of 5 and decrease machine background



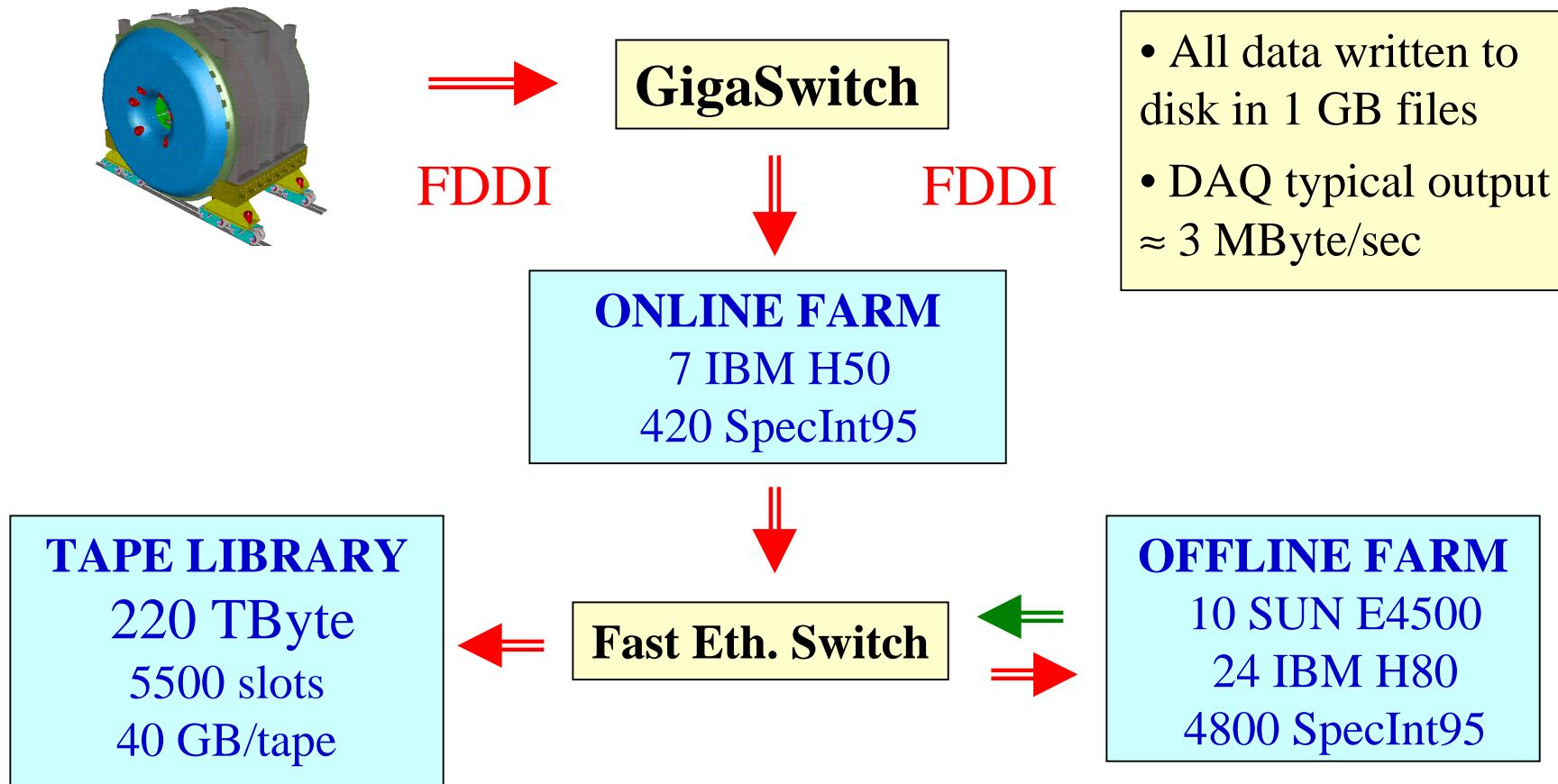
# KLOE trigger system

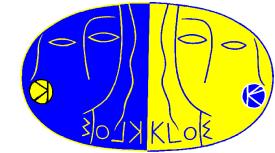
## The KLOE Trigger



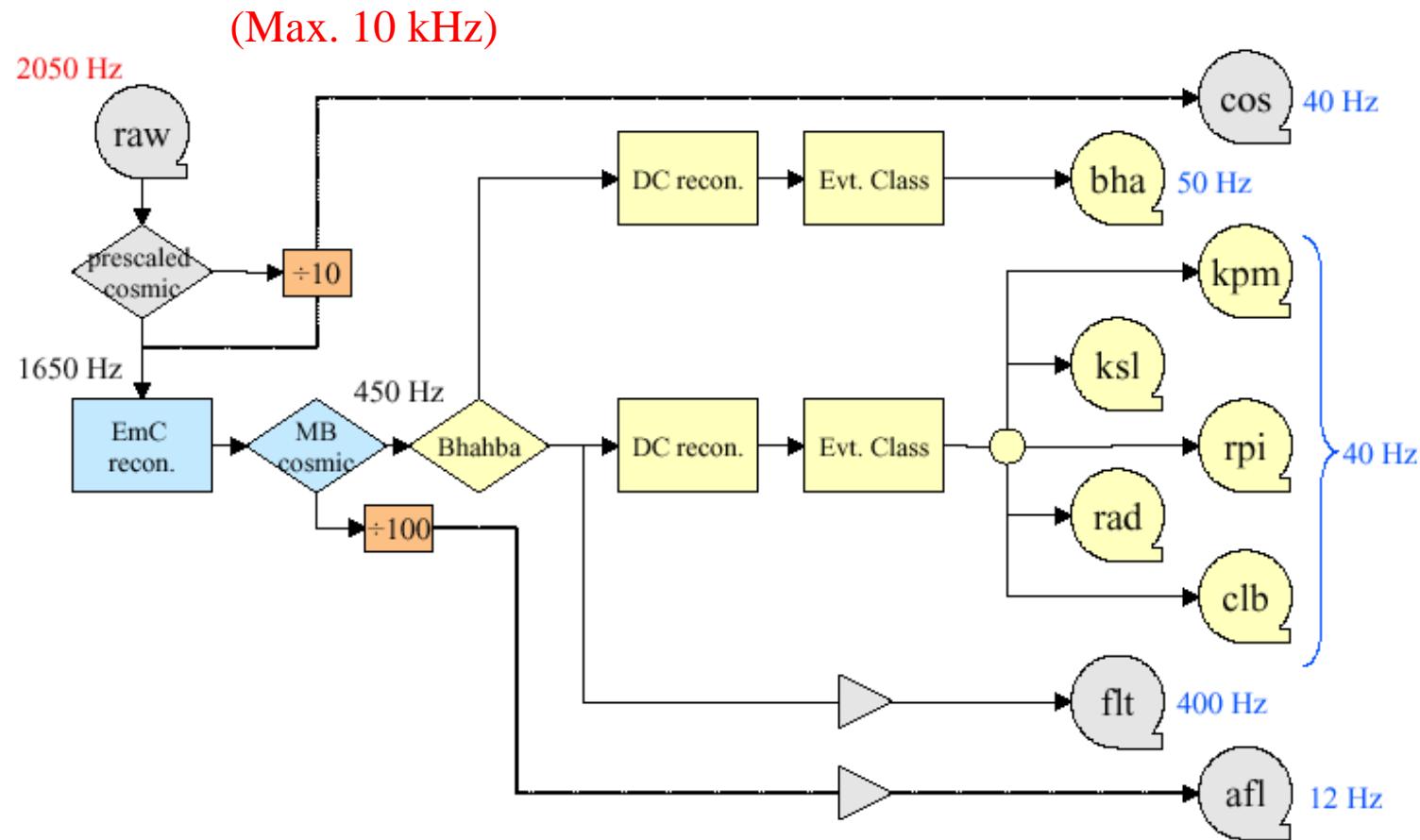


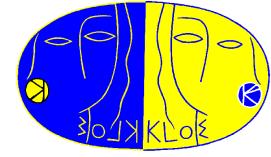
# KLOE data handling





# KLOE event streaming





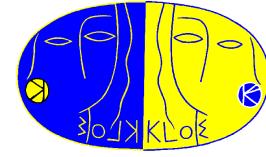
# KLOE physics

## Kaon Physics :

- Measurements of CP(T) violating parameters :
  - double ratio  $\text{Re}(\epsilon'/\epsilon)$
  - interferometry  $K_L, K_S \rightarrow f_1, f_2$
  - $K_S, K_L$  semileptonic asymmetries
- Kaon form factor ( $K_L \rightarrow \pi l\nu, K^+ \rightarrow \pi l^+\nu$ )
- Rare  $K_S$  decays ( $K_S \rightarrow \pi l\nu, K_S \rightarrow \pi ee, \pi \mu\mu, \pi \nu\nu, K_S \rightarrow 3\pi^0, K_S \rightarrow \pi^+ \pi^- \pi^0$ )
- Precision measurement of charged kaon decays
- Regeneration measurement at low momenta

## Non Kaon physics :

- radiative decays ( $\phi \rightarrow f_0\gamma, a_0\gamma, \eta\gamma, \eta'\gamma$ )
- $\sigma(e^+e^- \rightarrow \text{hadrons})$  for estimated the hadronic contribution to  $g-2$



# Analysis in progress

---

## Neutral kaon physics :

- $\text{BR}(\text{K}_s \rightarrow \pi^+ \pi^-) / \text{BR}(\text{K}_s \rightarrow \pi^0 \pi^0)$
- $\text{BR}(\text{K}_s \rightarrow \pi e \bar{\nu})$

## Charged kaon physics :

- $\text{BR}(\text{K}^\pm \rightarrow \pi^\pm \pi^0) / \text{BR}(\text{K}^\pm \rightarrow \mu^\pm \nu)$
- Preliminary studies of  $\text{K}^\pm$  branching ratios

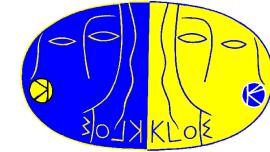
## Non kaon physics :

### Branching ratios :

- $\phi \rightarrow \pi^0 \gamma \rightarrow \gamma \gamma \gamma$
- $\phi \rightarrow \eta' \gamma, \phi \rightarrow \eta \gamma$
- $\phi \rightarrow f_0 \gamma \rightarrow \pi^0 \pi^0 \gamma$
- $\phi \rightarrow a_0 \gamma \rightarrow \eta \pi^0 \gamma$
- $\phi \rightarrow \pi^+ \pi^- \pi^0$

## Hadronic cross section :

- $\delta(e^+ e^- \rightarrow \pi^+ \pi^- \gamma)$



# Measurement of $\text{Re}(\epsilon'/\epsilon)$

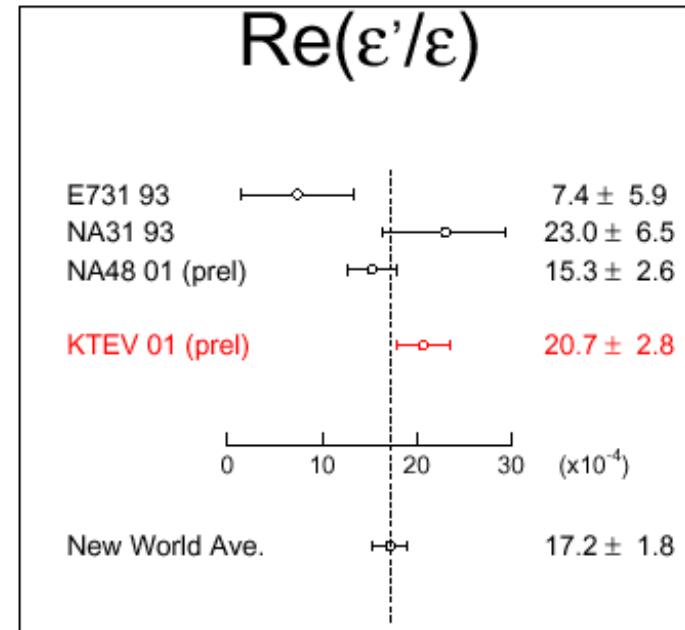
$$R = \frac{BR(K_L \rightarrow \pi^+ \pi^-) / BR(K_S \rightarrow \pi^+ \pi^-)}{BR(K_L \rightarrow \pi^0 \pi^0) / BR(K_S \rightarrow \pi^0 \pi^0)} = 1 - 6 \times \text{Re} \left( \frac{\epsilon'}{\epsilon} \right)$$

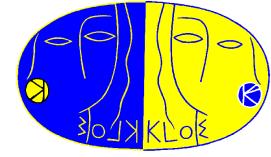
World average data (from LP 2001)

$$\text{Re}(\epsilon'/\epsilon) = (1.72 \pm 0.18) \times 10^{-3}$$

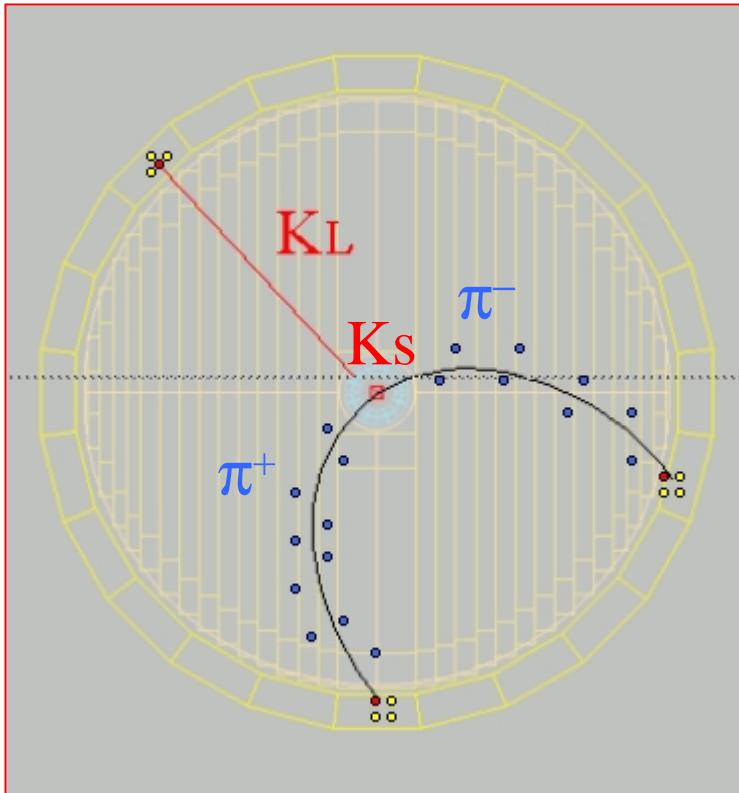
**KLOE** goal is to measure  
 $\text{Re}(\epsilon'/\epsilon)$  with a sensitivity  $\approx 10^{-4}$

- KLOE can measure all four modes for double ratio separately
- Ratio  $K_S \rightarrow \pi^+ \pi^- / K_S \rightarrow \pi^0 \pi^0$  already done





# Ks tagging : KL - crash



Ks tagging by identified with  
TOF KL interaction in EMC  
(Kcrash)

Nominal velocity of KL  
 $\beta \approx 0.218$

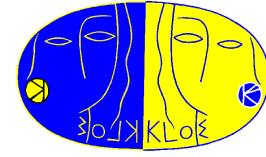
Selection cuts:

$$E_{\text{clust}} > 100 \text{ MeV}/c$$

$$|\cos(\theta_{\text{clust}})| \leq 0.7$$

$$0.195 \leq \beta \leq 0.247$$

Tagging efficiency  $\approx 30 \%$



# K<sub>s</sub>→π<sup>0</sup>π<sup>0</sup>, K<sub>s</sub>→π<sup>+</sup>π<sup>-</sup> selection

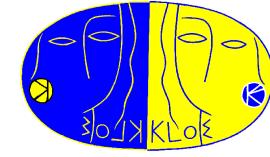
## K<sub>s</sub>→π<sup>0</sup>π<sup>0</sup> selection

- K crash
- 4 EMC clusters
- E<sub>γ</sub>> 20 MeV
- | t - R/C | < min(5δt, 3 ns)

## K<sub>s</sub>→π<sup>+</sup>π<sup>-</sup> selection

- Kcrash
- 2 track from IP
- $120 < p < 300 \text{ MeV/c}$  for rejection of  $\phi \rightarrow K^+K^-$  background
- $30^\circ < \Theta < 150^\circ$
- Both tracks impinged to EMC

- Acceptance estimated by Monte Carlo events
- Reconstruction, tagging, and trigger efficiencies estimated from data
- Estimated systematical errors

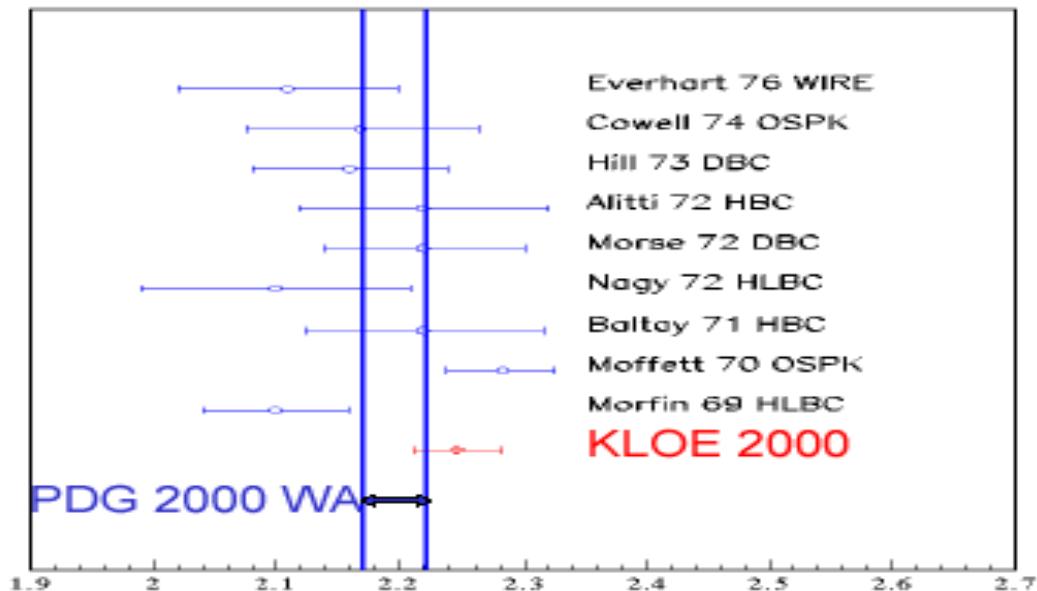


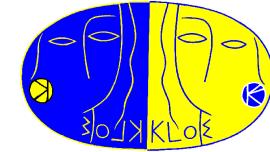
# Ratio $K_s \rightarrow \pi^+ \pi^- / K_s \rightarrow \pi^0 \pi^0$

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

KLOE Preliminary (2000) : Ratio =  $2.247 \times [1 \pm 0.2 \times 10^{-2} (\text{stat}) \pm 1.5 \times 10^{-2} (\text{syst})]$

Total contribution of systematics = 1.5 %

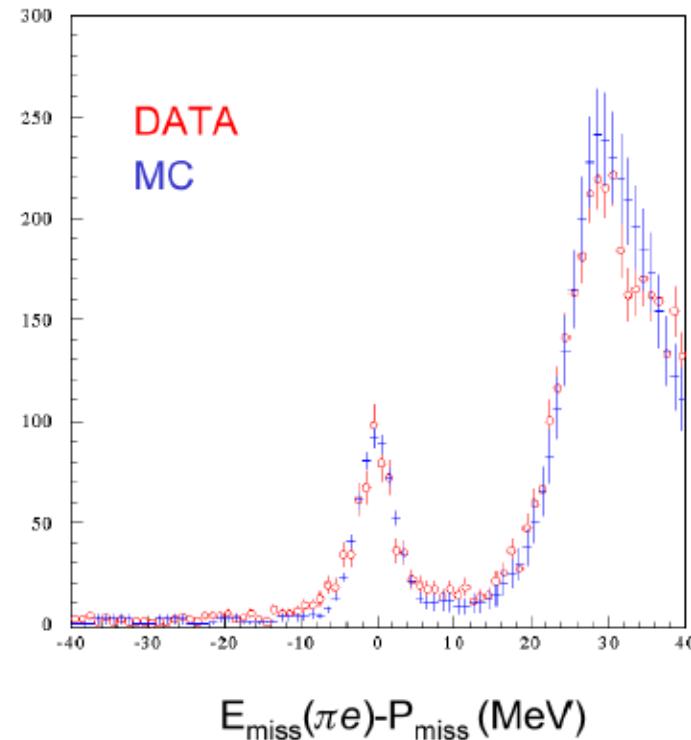




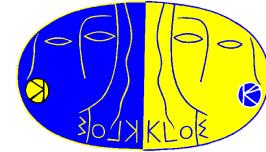
# K<sub>s</sub>→πeν analysis

## K<sub>s</sub>→πeν selection

- K-crash
- Kinematical preselection : two tracks from IP, cut on M(ππ) and P(K<sub>s</sub>)
- e /π TOF identification  $\Delta t(\pi,\pi) > 1.5$  ns and  $\Delta t(\pi,e) < 1$  ns,  $\Delta t(\pi,e) > 3$  ns
- Kinematical identification :  
 $E_{miss}(\pi,e) = E_s - E_\pi - E_e$   
 $P_{miss}(\pi,e) = P_s - P_\pi - P_e$
- Es and Ps of K<sub>s</sub> estimated by KL kinematics and  $\phi$  - boost
- Data fit used MC spectra for effect and background



Kinematic selection of K<sub>s</sub>→πeν by missing mass



# Branching ratio of $K_s \rightarrow \pi e \nu$

Total statistics :  $17 \text{ pb}^{-1}$   
(data 2000)  
Yield :  $627 \pm 30$  events

PDG (2000) :

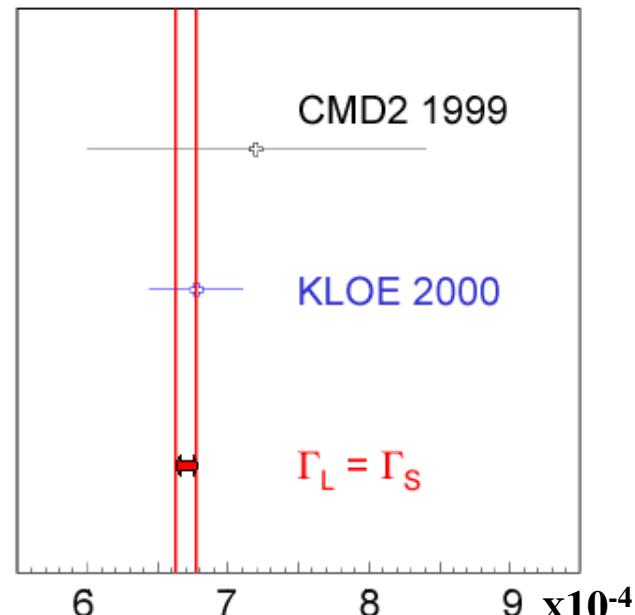
$\text{BR}(K_s \rightarrow \pi e \nu) = [7.2 \pm 1.4] \times 10^{-4}$   
(CMD2,  $75 \pm 13$  events)

$\Gamma(K_s \rightarrow \pi e \nu) = \Gamma(K_L \rightarrow \pi e \nu)$  :

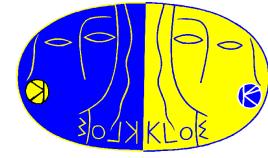
$\text{BR}(K_s \rightarrow \pi e \nu) = [6.70 \pm 0.07] \times 10^{-4}$

KLOE Preliminary (2000) :

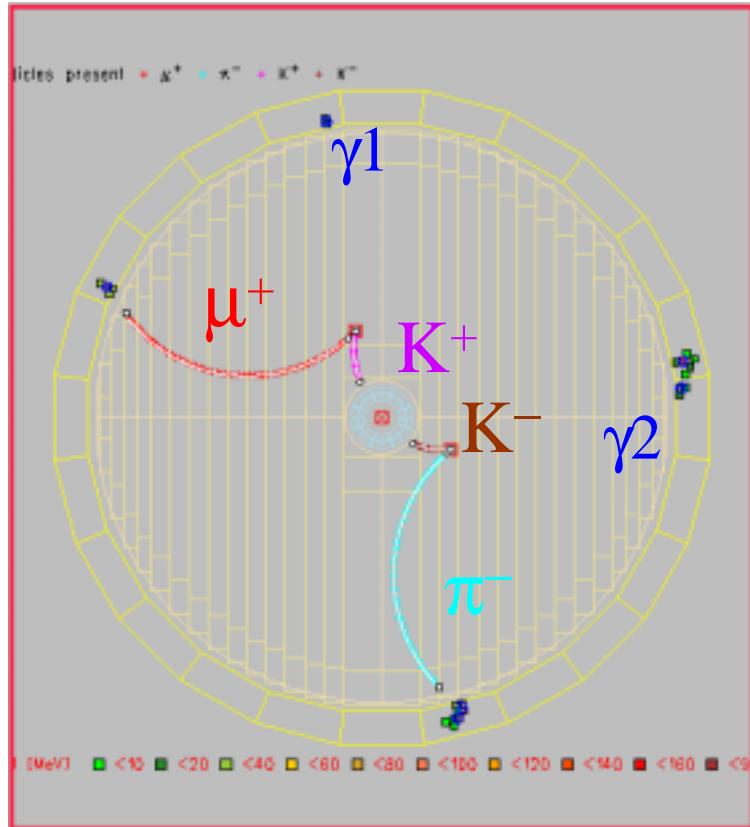
$\text{BR}(K_s \rightarrow \pi e \nu) = [6.8 \pm 0.3 \text{ (stat)}] \times 10^{-4}$



Branching ratio  $K_s \rightarrow \pi e \nu$



# Charged kaon's physics

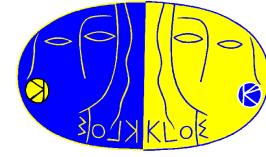


Two body decays in  $K^+K^-$ - stream

Main BR for  $K^+K^-$  decays

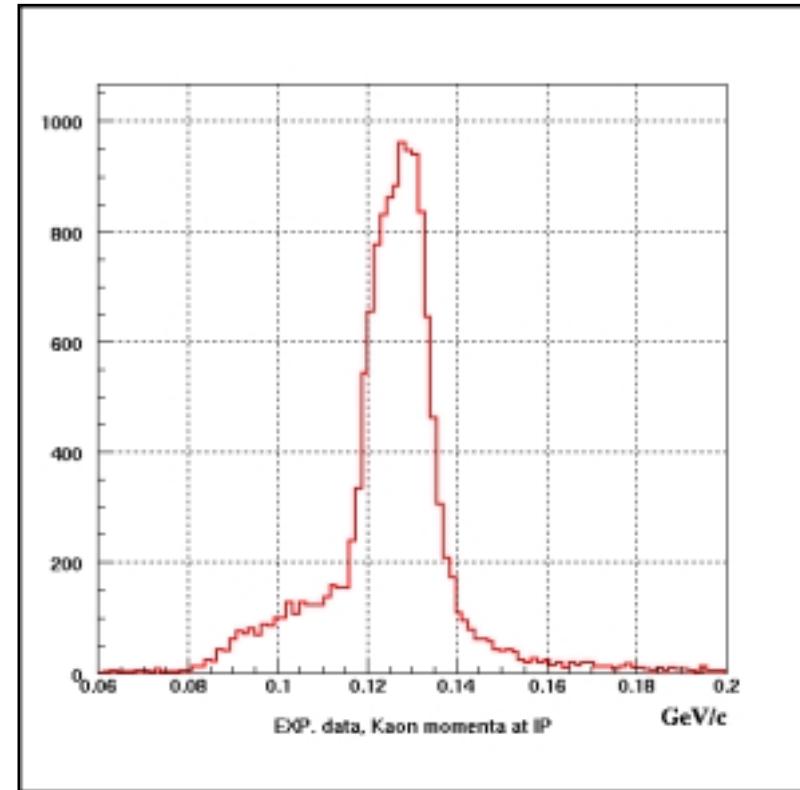
$\mu^\pm\nu$	63.51 %
$\pi^\pm\pi^0$	21.16 %
$\pi^\pm\pi^+\pi^-$	5.59 %
$e^\pm\pi^0\nu$	4.82 %
$\mu^\pm\pi^0\nu$	3.18 %
$\pi^\pm\pi^0\pi^0$	1.73 %

For 80 pb<sup>-1</sup> we have approx.  
 $50*10^6 \phi \rightarrow K^+K^-$

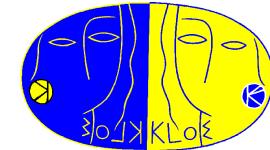


# K track selection

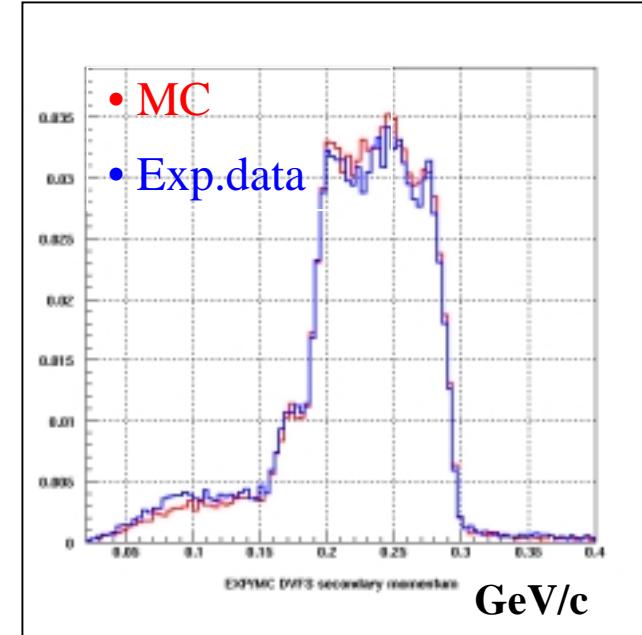
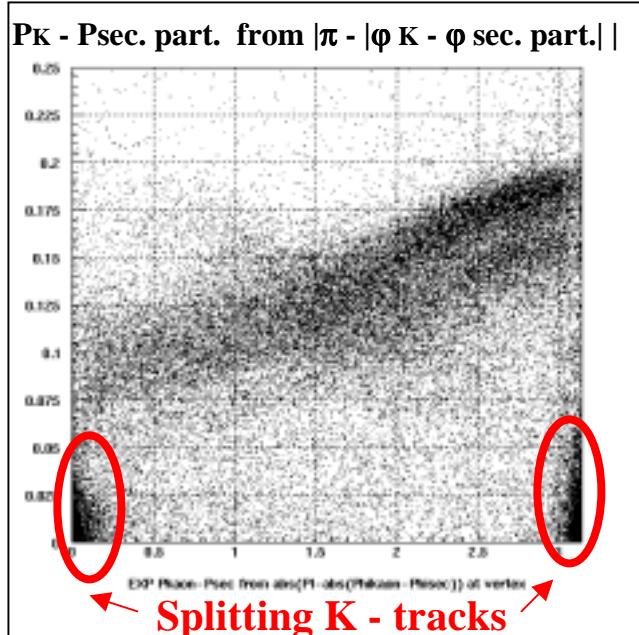
- Investigation MC and exp. data after track fit procedure
  - Using filter (**KPMFILT**) for selection  $\phi \rightarrow K^+K^-$  events (based on 4 different procedures and 2 vetoes algorithm to reduce possible contamination)
  - $K^+K^-$  stream includes  $\approx 30\%$  machine background non correlated with kaon physics



$K^+K^-$  momentum at interaction point



# Secondary vertex selection

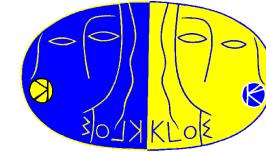


## Cut for secondary vertex

- K $^\pm$  candidate from KPMFILT
- | P<sub>K</sub> - Psec. part. | < 40 MeV
- 0.14 < | $\pi$  - | $\phi$  K -  $\phi$  sec. part.| | < 3.0

## Secondary momentum

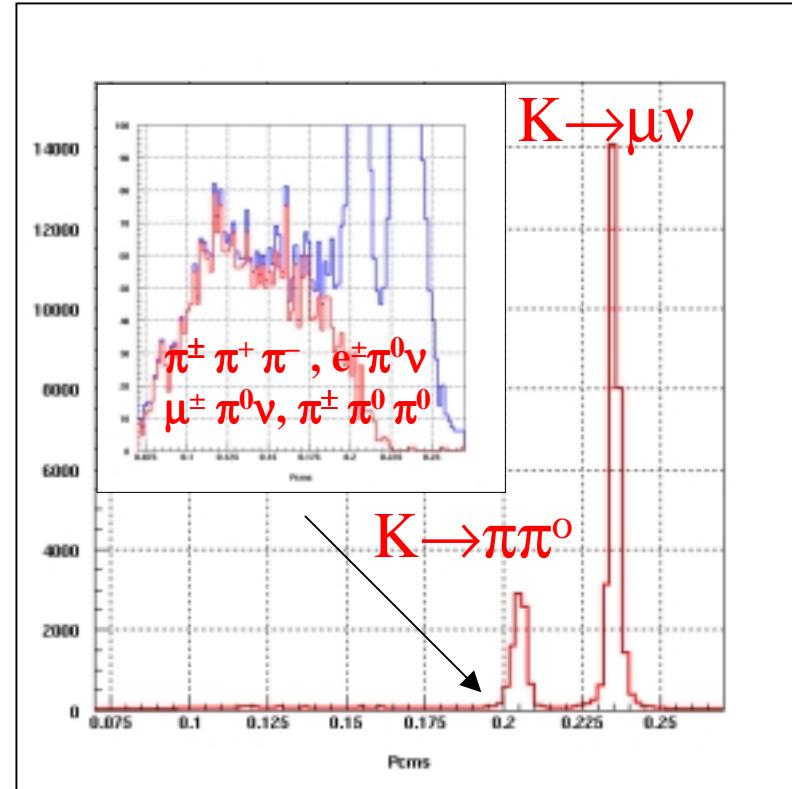
- Good agreement of MC and EXP - data
- Differences : region  $\approx$  100 MeV/c (rare K - decays, not implemented for MC)



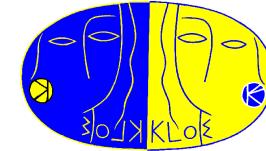
# Ratio $K \rightarrow \pi\pi^0 / K \rightarrow \mu\nu$

## Ratio tagging

- $\mu^\pm$  peak window  
 $225 \text{ MeV}/c < P_{CM} < 245 \text{ MeV}/c$
- $\pi^\pm$  peak window  
 $195 \text{ MeV}/c < P_{CM} < 215 \text{ MeV}/c$
- Decay vertex with  $R_{xy} > 40 \text{ cm}$
- For good trigger efficiency : one kaon track has a decay  $K \rightarrow \pi\pi^0$
- Cut for secondary vertex and secondary momentum  
 $20 \text{ MeV}/c < P_{sec} < 400 \text{ MeV}/c$
- Cut for kaon momentum at decay point     $80 \text{ MeV}/c < P_K < 120 \text{ MeV}/c$



C.M. momentum spectrum for  $K^\pm$

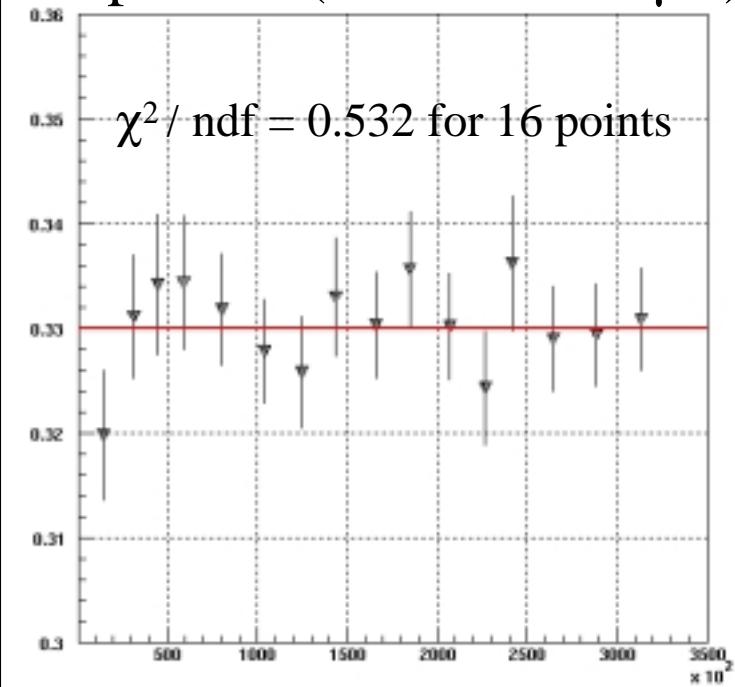


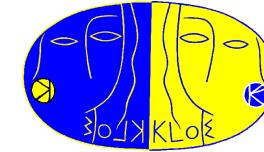
# Ratio $K \rightarrow \pi\pi^0 / K \rightarrow \mu\nu$

Total statistics : **11.2 pb<sup>-1</sup>**  
(end 2000)

- Ratio = (Exp. Ratio)  $\times$  MC coeff.  $\times C\gamma$
- Exp. ratio =  $0.3300 \pm 0.0013$
- Exp. + MC corr. =  $0.3326 \pm 0.0013$
- Correction for  $K \rightarrow \mu\nu\gamma$  decay ( $C\gamma = 0.994$ )
- Ratio =  $0.3306 \pm 0.0012$  (stat)
- Systematic error should not exceed 2 %  
, its precise evaluation is underway

Exp. ratio ( $K \rightarrow \pi\pi^0 / K \rightarrow \mu\nu$ )





# Ratio $K \rightarrow \pi\pi^0 / K \rightarrow \mu\nu$

## World data

$0.3331 \pm 0.0028$  (fit)

$0.3316 \pm 0.0032$  (Average) (PDG)

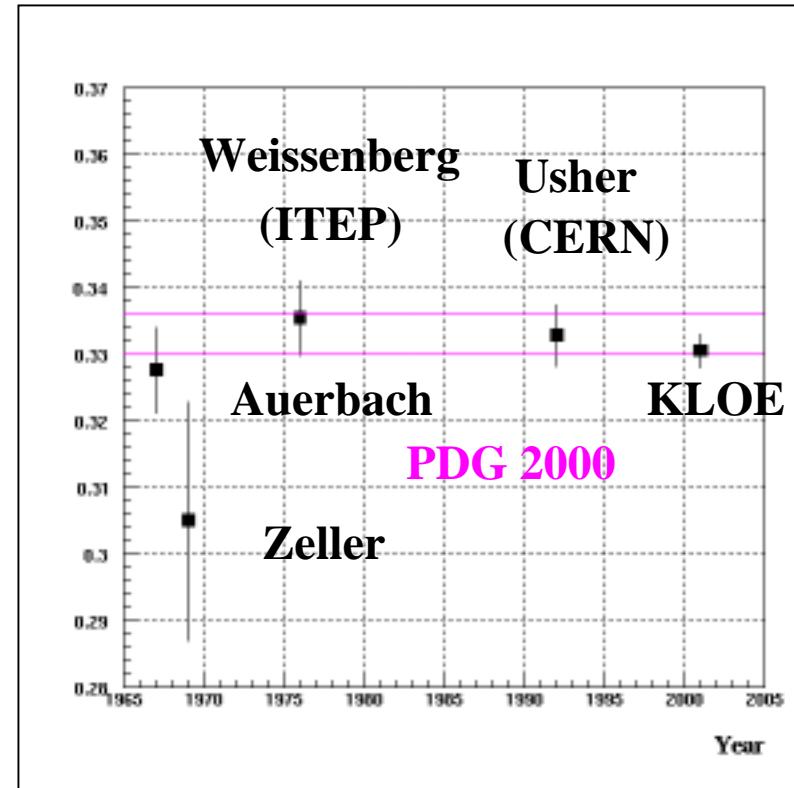
•  $0.3329 \pm 0.0047$  (USHER - 1992)

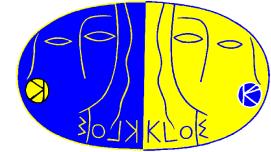
•  $0.3355 \pm 0.0057$  (WEISSENBERG - 1976)

•  $0.305 \pm 0.018$  (ZELLER - 1969)

•  $0.3277 \pm 0.0065$  (AERBACH - 1967)

$0.3306 \pm 0.0012$  (stat.) (KLOE  
preliminary)





# Conclusion and perspective

- In year 2000 was collected total statistics  $\approx 25 \text{ pb}^{-1}$
- Physics runs showed a good performance of the KLOE detector
- Results have been presented on  $K_s \rightarrow \pi^+ \pi^- / K_s \rightarrow \pi^0 \pi^0$ ,  $K_s \rightarrow \pi e \nu$ , and  $K \rightarrow \pi \pi^0 / K \rightarrow \mu \nu$
- In all cases the present PDG values are considerably improved
- DAFNE is improving its performance every year
- In 2001 we have  $\approx 58 \text{ pb}^{-1}$  and expected  $\approx 200 \text{ pb}^{-1}$  up to the end of 2001