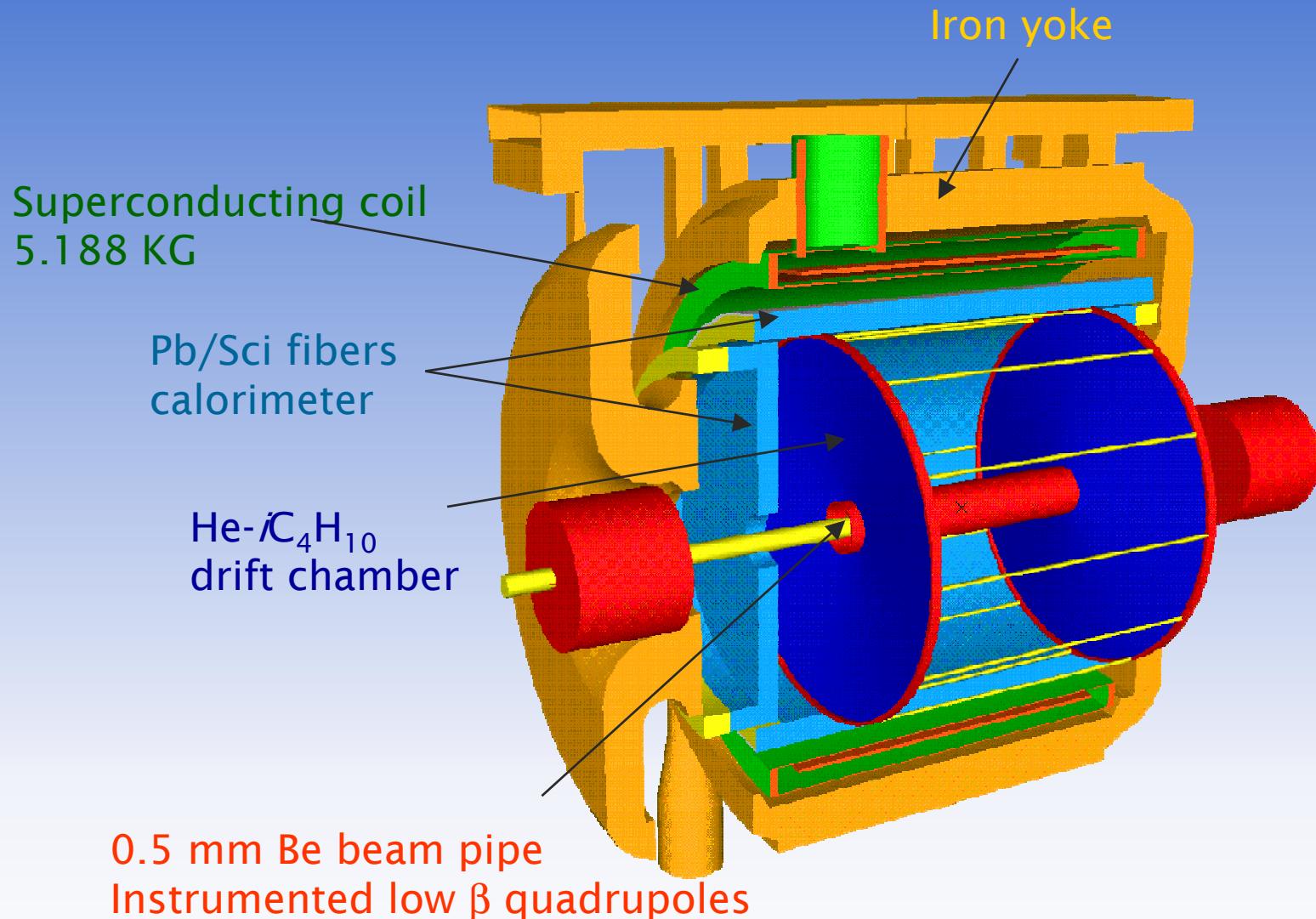




The KLOE Physics Program

1





φ-factory Physics

2

e^+e^- , $\sqrt{S} = 1020$ MeV $\cong M_\phi$, $J^{PC} = 1^-$

Totally asymmetric wave function:

$$| i \rangle = \frac{K_S(p)K_L(-p)-K_S(-p)K_L(p)}{\sqrt{2}}$$

Pure & monochromatic Kaon beams, $p_K=110$ MeV/c

$$\lambda(K_S) = 6 \text{ mm } (\tau=51.7 \text{ ns})$$

$$\lambda(K_L) = 3.5 \text{ m } (\tau=90 \text{ ps})$$

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

- ❖ Tagging the presence of one K by observing the other
- ❖ Pure (to 10^{-5}) K_S beam, unique to DAΦNE
→ rare K_S decays
- ❖ Interferometry



ϵ'/ϵ with Double Ratio

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

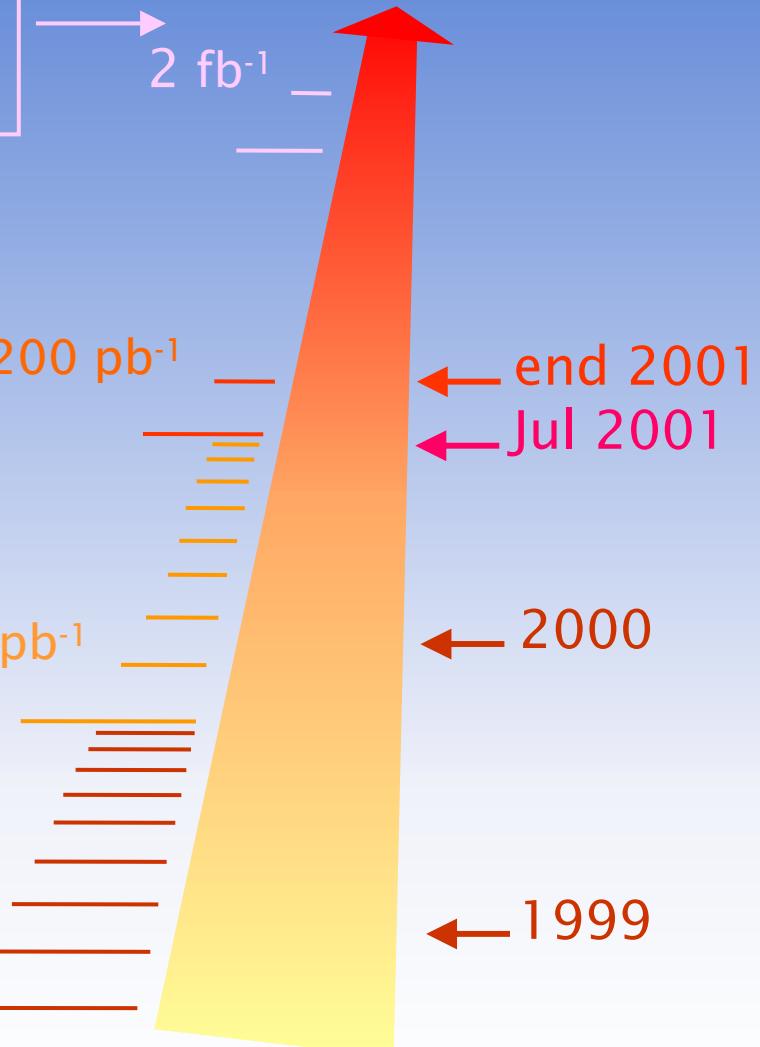
- ❖ KLOE can measure K_S and K_L decays separately:
(all 4 modes in the double ratio)
- ❖ Competitive $\text{BR}(K_S \rightarrow \pi^+ \pi^-) / \text{BR}(K_S \rightarrow \pi^0 \pi^0)$ measurement
already done with low integrated luminosity



Luminosity arrow

4

ε'/ε to few 10^{-4}
Interferometry
CPT test, semileptonic asymmetry



σ^{hadr} to 1% (stat)
Rare K_S decays

K_S physics
 ϕ radiative decays



Data yield with 200 pb⁻¹

5

❖ K_S 2×10^8

0.6×10^8 tagged (K_L visible Interactions)

$K_S \rightarrow \pi^+ \pi^-$ $0.3 \times 10^8 \cdot BR$ $\sim 2 \times 10^7$

$K_S \rightarrow \pi^0 \pi^0$ $0.3 \times 10^8 \cdot BR$ $\sim 1 \times 10^7$

$K_S \rightarrow \pi e \nu$ $0.9 \times 10^7 \cdot BR$ ~ 6700

$K_S \rightarrow \gamma \gamma$ $3.3 \times 10^7 \cdot BR$ ~ 70

$K_S \rightarrow \pi^0 e^+ e^-$ (Single Event Sensitivity) $0.8-1.5 \times 10^{-7}$

$K_S \rightarrow \pi^0 \pi^0 \pi^0$ (Single Event Sensitivity) 3×10^{-8}

❖ K_L 2×10^8

0.9×10^8 tagged ($K_S \rightarrow \pi^+ \pi^-$)

K_L Decay in FV (D.C.) 2.5×10^7

$K_L \rightarrow \pi^+ \pi^-$ $\sim 2.7 \times 10^4$

$K_L \rightarrow \pi^0 \pi^0$ $\sim 1.0 \times 10^4$

$K_L \rightarrow \gamma \gamma$ $\sim 0.5 \times 10^4$

❖ $K^{+/-} 3 \times 10^8$

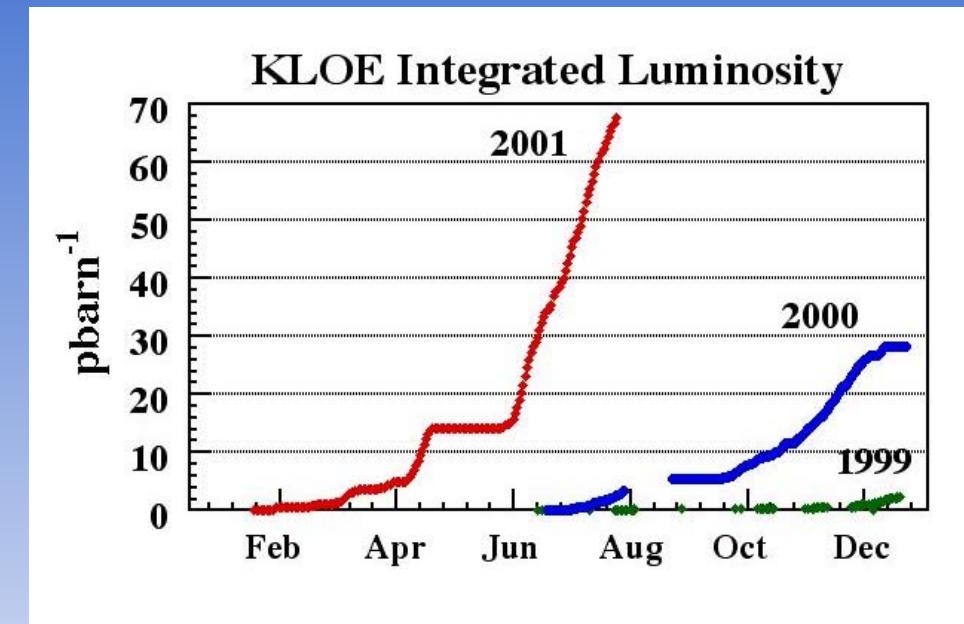
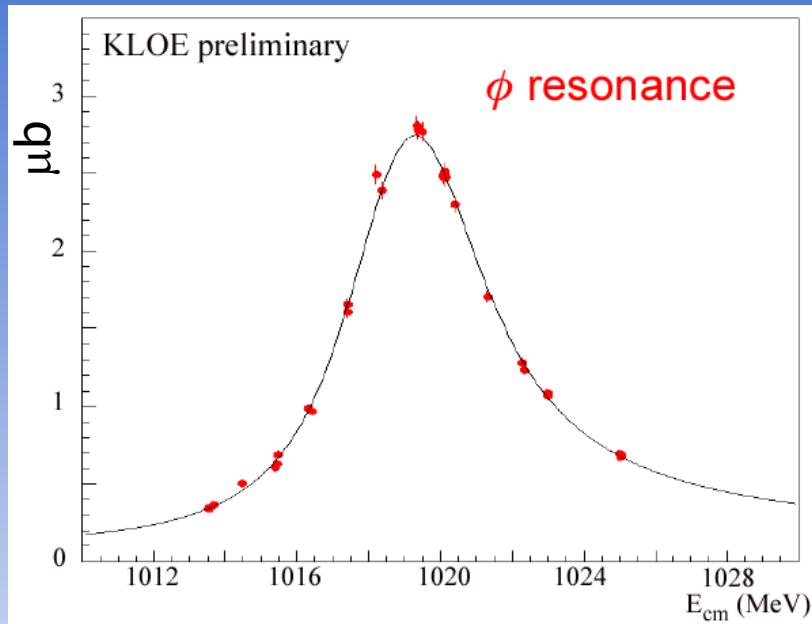
0.7×10^8 tagged

Reconstructed K^+ (K^-) 5×10^7



DAΦNE performance

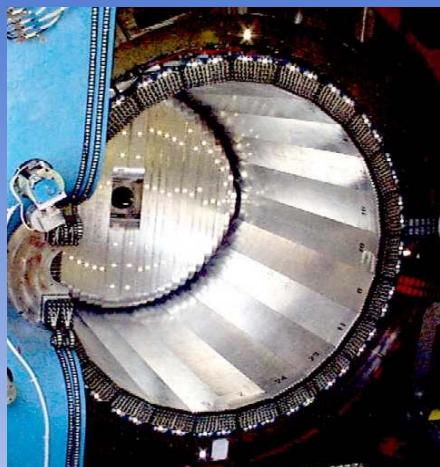
6



- Peak luminosity exceeded $3 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
- Integrated luminosity exceeded $1.5 \text{ pb}^{-1}/\text{day}$
- Expected total integrated luminosity in 2001: 200 pb^{-1}
- Interaction region upgrade mid 2002



KLOE detector performance



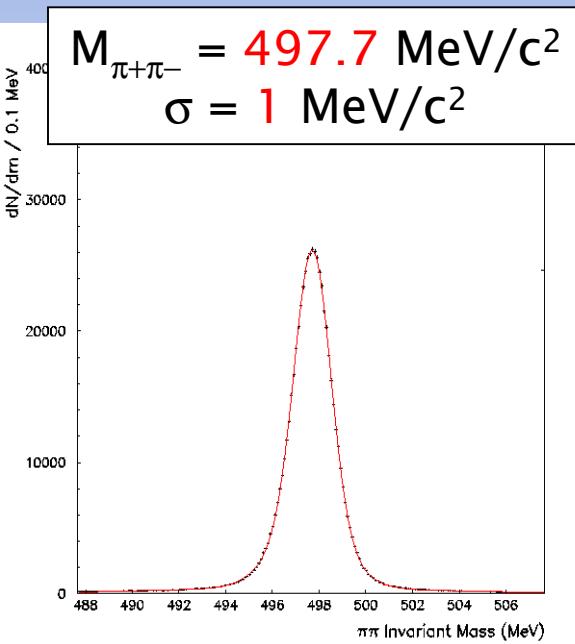
$$\sigma_E/E = 5.7\% / \sqrt{E(\text{GeV})}$$

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

(bunch length contribution subtracted)

$$\sigma_{xy} = 1.2 \text{ cm}$$

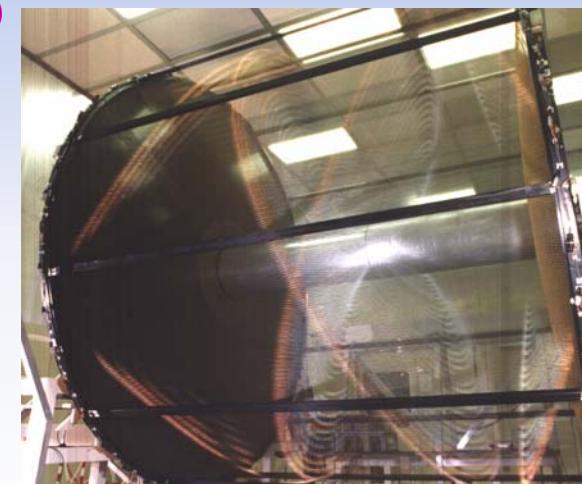
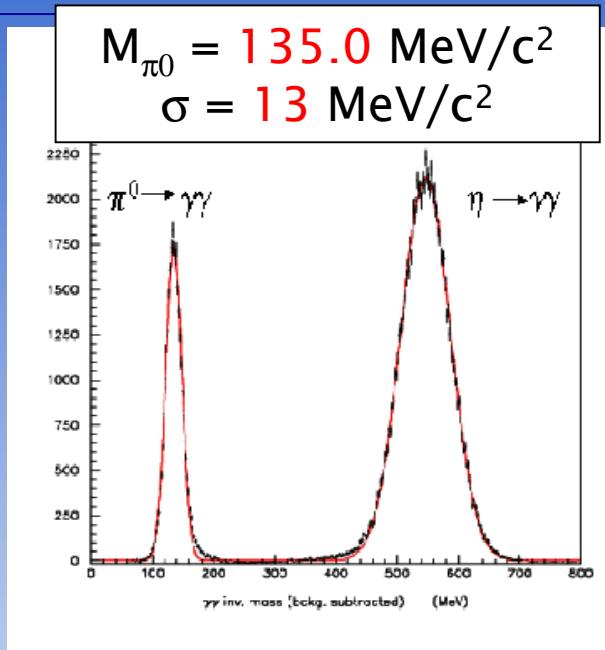
$$\sigma_z = 1.2 / \sqrt{E(\text{GeV})}$$



$$\sigma_p/p = 0.4 \% \text{ (for } 90^\circ \text{ tracks)}$$

$$\sigma_{xy} \approx 150 \mu\text{m}$$

$$\sigma_z \approx 2 \text{ mm}$$





Highlights of 2000 data analysis

8

❖ Neutral Kaon physics

- ❖ $\text{BR}(K_S \rightarrow \pi^+\pi^-) / \text{BR}(K_S \rightarrow \pi^0\pi^0)$
- ❖ $K_S \rightarrow \pi e \nu$
- ❖ preliminary studies of $K_L \rightarrow \pi\pi$

❖ Charged Kaons

- ❖ preliminary studies of K^\pm BRs

❖ Non Kaon physics

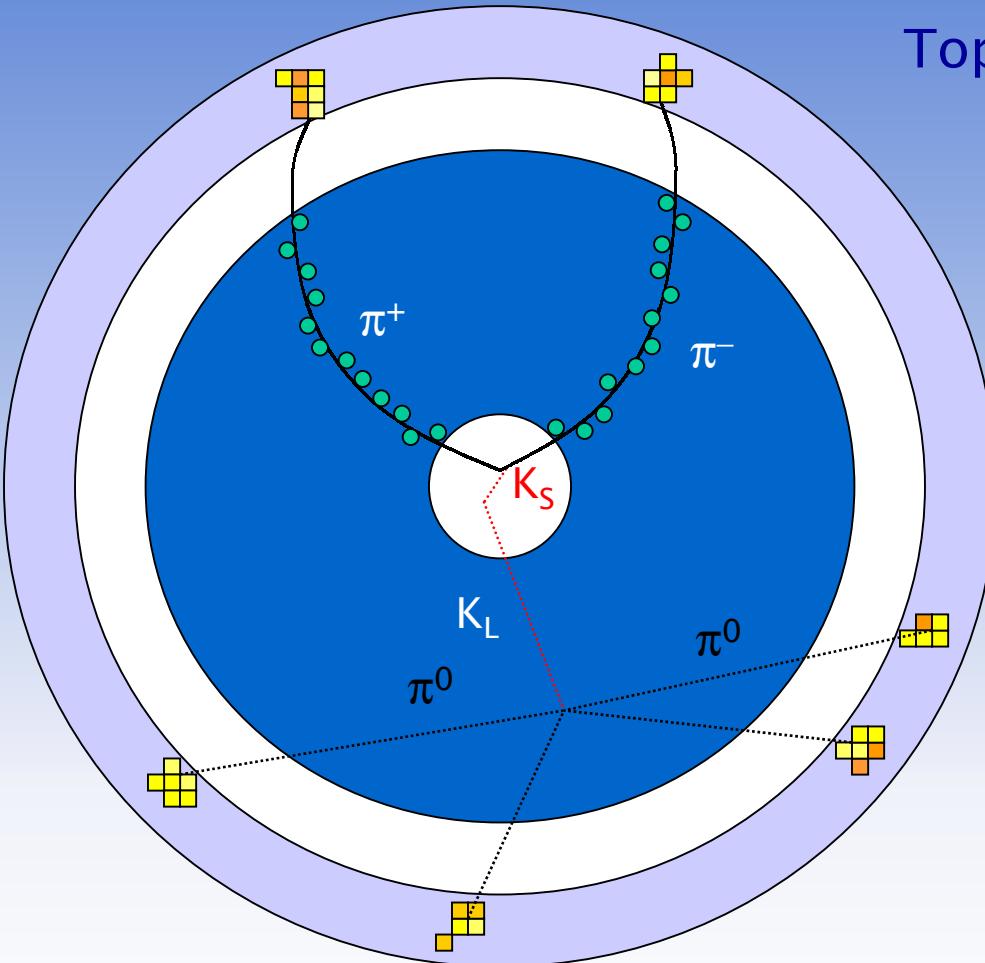
- ❖ $\eta - \eta'$ mixing
- ❖ $\phi \rightarrow f^0\gamma \rightarrow \pi^0\pi^0\gamma$
- ❖ $\phi \rightarrow a^0\gamma \rightarrow \eta\pi^0\gamma$
- ❖ $\phi \rightarrow \pi^+\pi^-\pi^0$

❖ Hadronic cross section



K_L tagging: $K_S \rightarrow \pi^+ \pi^-$

9



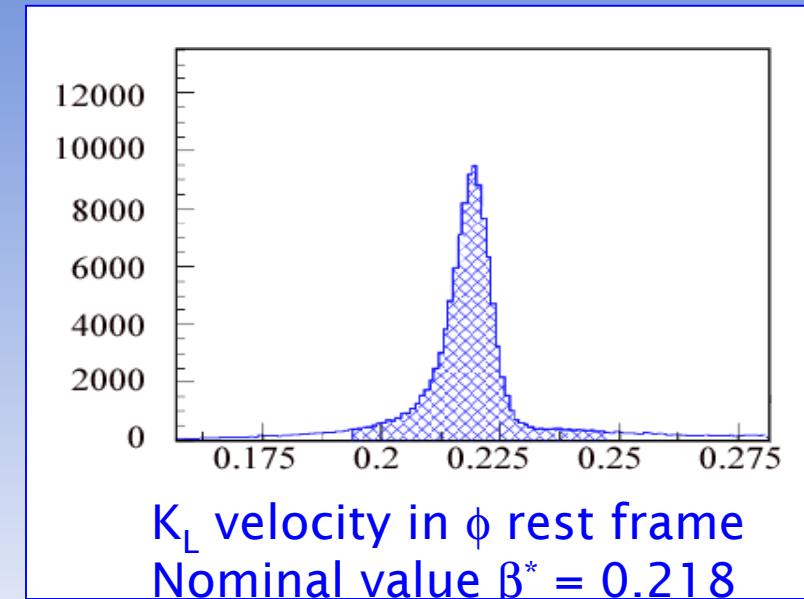
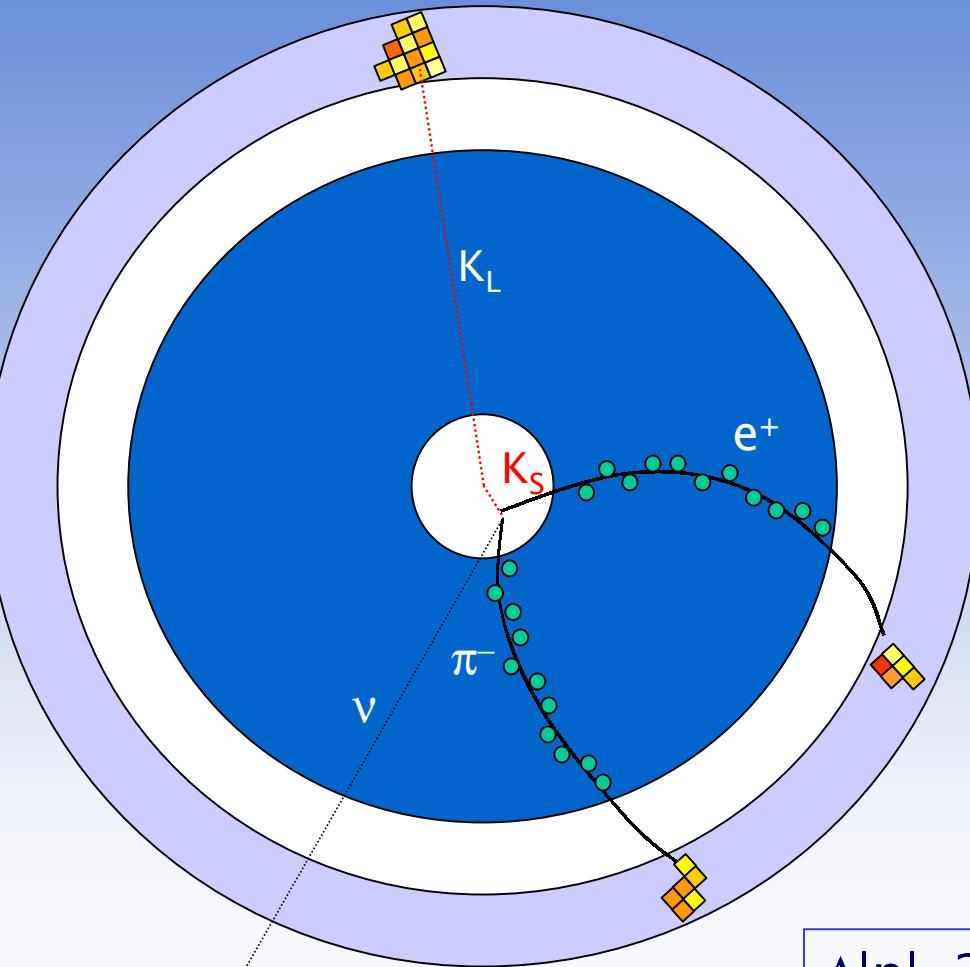
Topological cuts, loose p cut

$$\epsilon_{\text{TAG}} \sim 46 \%$$



K_S tagging: K_L interacting in calorimeter 10

Time-of-flight identification of K_L interacting in the calorimeter



$\Delta|p|=2\text{MeV}/c$; $\Delta\theta_S=2^\circ$
 $\varepsilon_{\text{TG}} \sim 30\%$



Time of flight

11

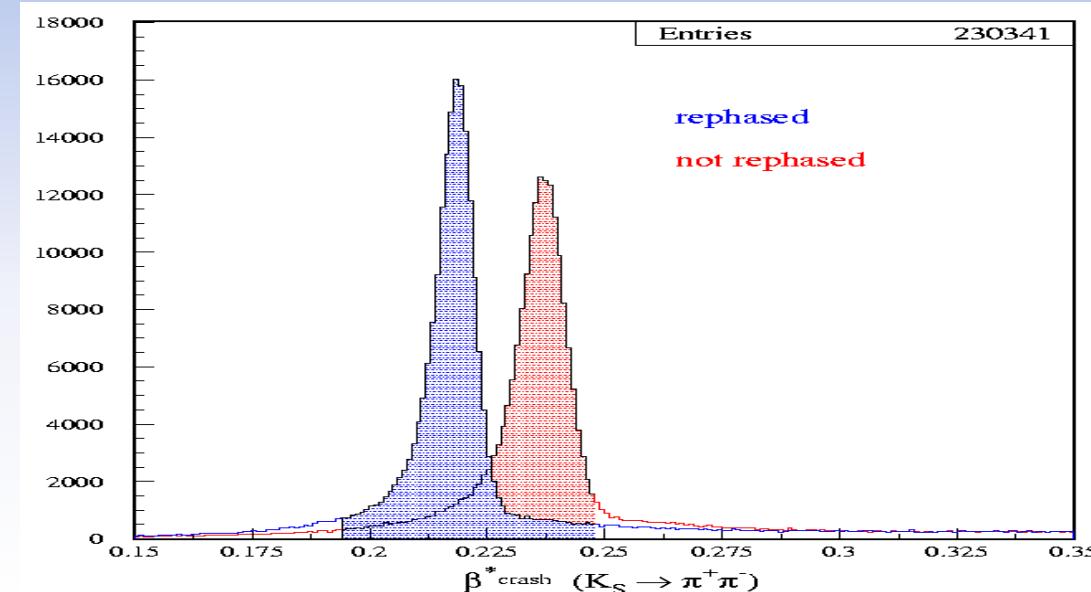
To get particle TOF, the global event t_0 is needed:

- The trigger is synchronized with an *integer multiple of the bunch crossing frequency*
- Correct crossing evaluated offline by looking at the fastest cluster in the event

The tag efficiency is evaluated from data:

slightly dependent on K_S decay mode, due to the different t_0 estimates

$$\varepsilon^+ / \varepsilon^{00} = (95.030 \pm 0.005) \%$$





- ❖ K_S tag (K_L interaction)
- ❖ $\text{K}_S \rightarrow \pi^+\pi^-$ selection
- ❖ $\text{K}_S \rightarrow \pi^0\pi^0$ selection
- ❖ Correct for efficiencies



- Acceptance from Monte Carlo
- All other efficiencies from data
- Estimate systematics

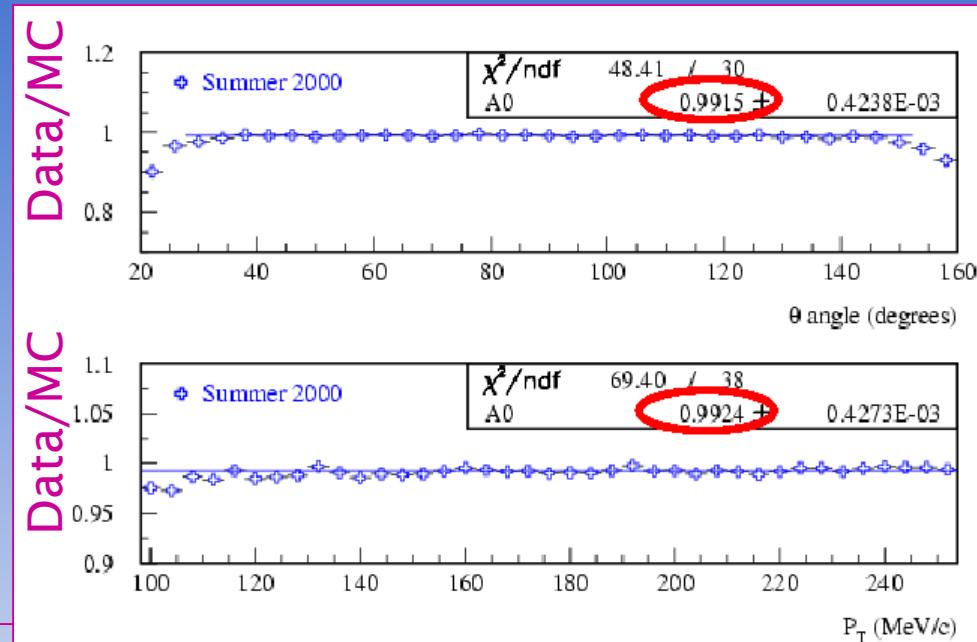


Selection

- ❖ K_S tag (K_L interaction)
- ❖ 2 tracks coming from the IP
 $d_{xy} < 4$ cm, $|z| < 10$ cm
- ❖ Acceptance and loose p cuts

Efficiencies

- Acceptance from Monte Carlo
- Tag efficiency from data
- Tracking efficiency from data
- t_0 and trigger efficiencies:
 - Single particle efficiencies from data
($K_S \rightarrow \pi^+ \pi^-$ sub samples, $K_L \rightarrow \pi e \nu$)
 - Plug in MC



$$\varepsilon_+(\text{selection}) = (58.5 \pm 0.1) \%$$
$$\varepsilon_+(t_0 \cdot \text{trigger}) = (96.5 \pm 0.5) \%$$

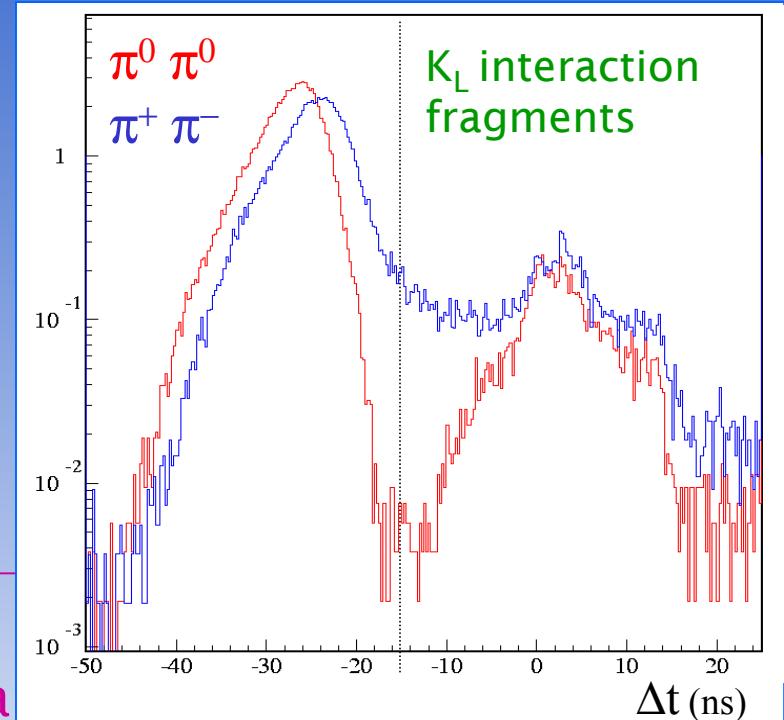


Selection

- ❖ K_S tag (K_L interaction)
- ❖ 4 prompt clusters by TOF
- ❖ Acceptance and E cuts

Efficiencies

- Acceptance from Monte Carlo
- Photon detection efficiency from data using $\phi \rightarrow \pi^+ \pi^- \pi^0$ control samples
- Trigger efficiency:
 - Measure probability of having 0,1 triggering clusters from data
 - Compute trigger efficiency



$$\varepsilon_{00}(\text{selection}) = (56.7 \pm 0.1) \%$$
$$\varepsilon_{00}(t_0 \cdot \text{trigger}) = (99.69 \pm 0.03) \%$$



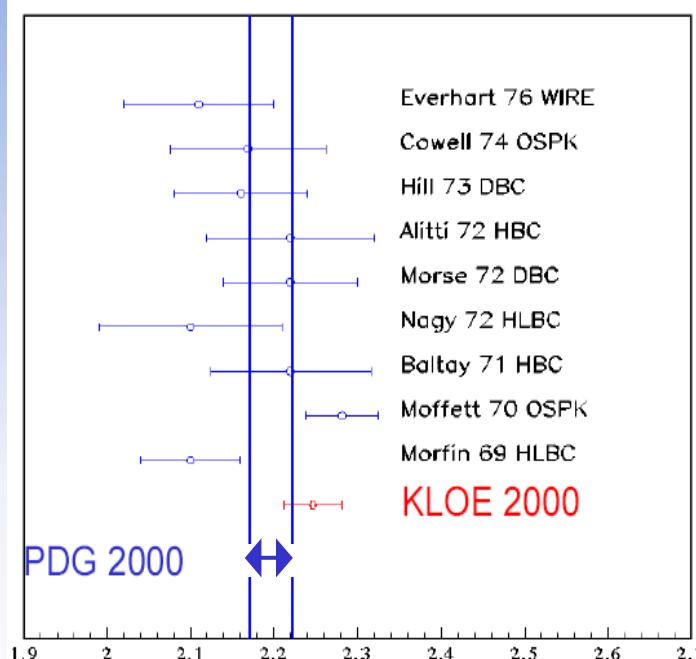
$$r = \text{BR}(\text{K}_S \rightarrow \pi^+ \pi^-) / \text{BR}(\text{K}_S \rightarrow \pi^0 \pi^0)$$

KLOE 2000 preliminary

$$r = 2.247 \times [1 \pm 0.2 \times 10^{-2}(\text{stat}) \pm 1.5 \times 10^{-2}(\text{syst})]$$

PDG 2000

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



Contribution to systematics	%
Tag bias	1
$\text{K}_S \rightarrow \pi^0 \pi^0$ selection	1
$\text{K}_S \rightarrow \pi^0 \pi^0$ trigger	0.02
$\text{K}_S \rightarrow \pi^+ \pi^-$ selection	0.1
$\text{K}_S \rightarrow \pi^+ \pi^-$ trigger and t_0	0.5
Total	1.5

Systematics under study
to reduce tag bias contribution



- ❖ K_S tag (K_L interaction) & Kinematic preselection
- ❖ Track/cluster association (TCA)

Efficiencies

- Acceptance ($\epsilon = 51.1\%$) and preselection ($\epsilon = 62.4\%$) from Monte Carlo
- t_0 , TCA and trigger efficiencies estimated directly from data using several control samples ($\epsilon_{TCA+T0+TRG} = 81.7\%$):
 $K_L \rightarrow \pi e \nu$ (before DC), $\phi \rightarrow \pi^+ \pi^- \pi^0$, $K_S \rightarrow \pi^+ \pi^-$

- ❖ π/e identification using time-of-flight
- ❖ Kinematically close the event using p_K to get p_ν final selection & fit
- ❖ Correct for efficiencies
- ❖ Normalize to $K_S \rightarrow \pi^+ \pi^-$



$K_S \rightarrow \pi e \nu$: π/e identification by TOF

17

- Build the combinations:

$$\delta t = t - L / (\beta c) \text{ in } e \text{ and } \pi \text{ hypothesis for the 2 particles}$$

- Cut in δt difference:

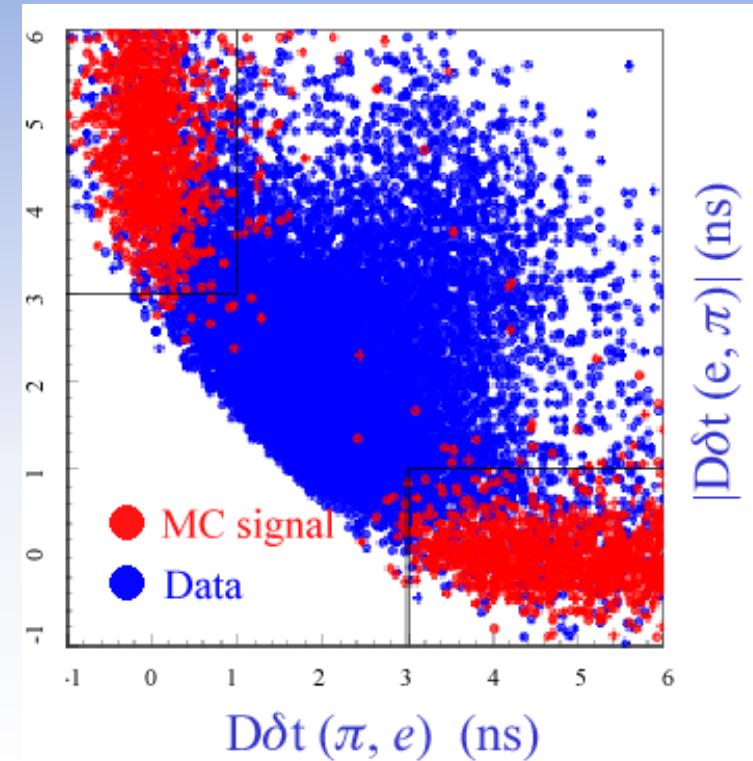
$$D\delta t(1,2) = |t - L / (\beta(m_1)c) - t - L / (\beta(m_2)c)|$$

Efficiency

Selection efficiency from $K_L \rightarrow \pi e \nu$ data
(decaying before DC)

$$D\delta t(\pi, \pi) > 1.5 \text{ ns}$$

$$D\delta t(\pi, e) < 1 \text{ ns}; D\delta t(e, \pi) > 3 \text{ ns}$$





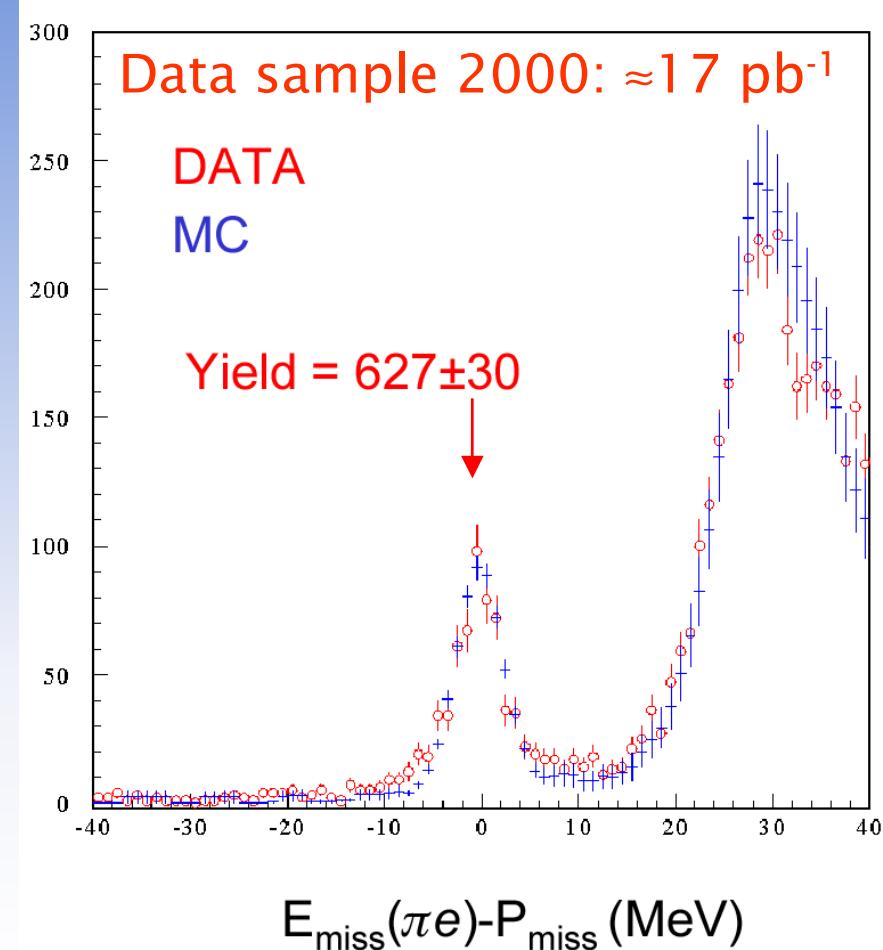
$K_S \rightarrow \pi e \nu$ yield

18

Final signal selection in the variable $E_{\text{miss}} - P_{\text{miss}}$ (must be 0 for neutrino)

Overall selection efficiency: $\epsilon_{\text{TOT}} = (21.8 \pm 0.3)\%$

Fit performed on **data** using MC
spectra for $\pi^+\pi^-$ background & signal





BR($K_S \rightarrow \pi e v$)

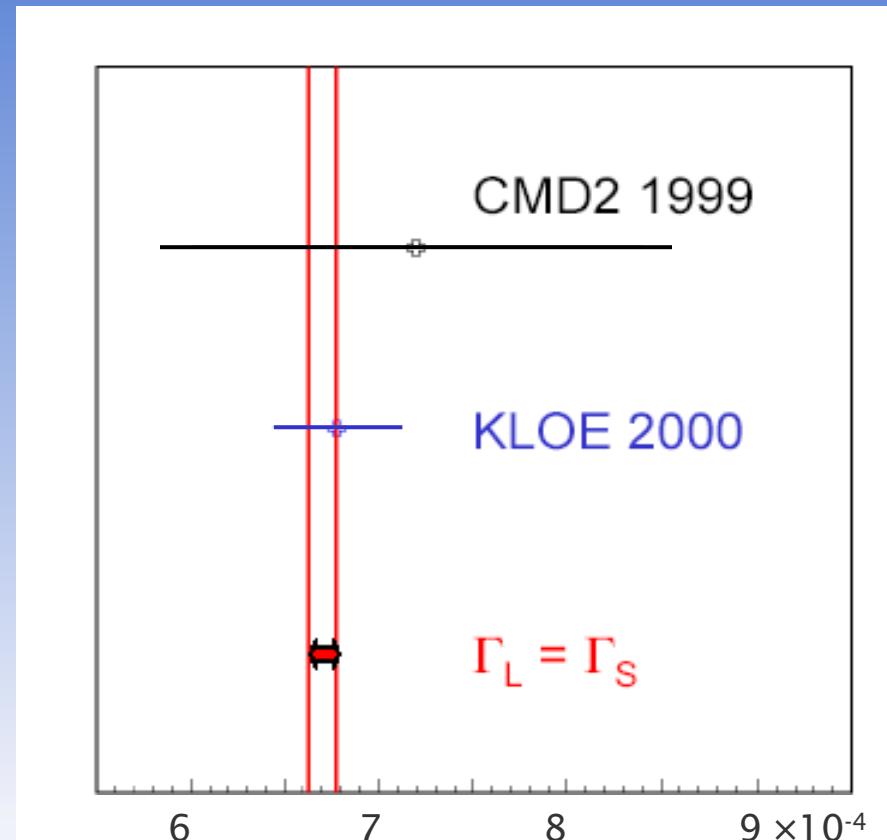
19

KLOE preliminary result
 $[6.8 \pm 0.3(\text{stat})] \times 10^{-4}$

systematics <10%,
precise evaluation under way

PDG2000 (CMD2, 75 ± 13 events):
 $(7.2 \pm 1.4) \times 10^{-4}$

Assuming $\Gamma_L(\pi e v) = \Gamma_S(\pi e v)$
 $(6.70 \pm 0.07) \times 10^{-4}$





ϕ radiative decays

20

$$\text{BR}(\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma) = [7.9 \pm 0.2(\text{stat})] \times 10^{-5}$$

$$\text{BR}(\phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma) = [5.8 \pm 0.5(\text{stat})] \times 10^{-5}$$

$$\text{BR}(\phi \rightarrow \eta\pi^0\gamma) = [6.7 \pm 0.9(\text{stat})] \times 10^{-5} \quad (\eta \rightarrow \pi^+\pi^-\pi^0)$$

assuming $\text{BR}(\phi \rightarrow f_0\gamma) \approx 3 \times \text{BR}(\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma)$ and $\text{BR}(\phi \rightarrow a_0\gamma) \approx \text{BR}(\phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma)$, correspond to

$$\text{BR}(\phi \rightarrow f_0\gamma)/\text{BR}(\phi \rightarrow a_0\gamma) = 4.1 \pm 0.4 \text{ (stat)}$$

Systematics: precise evaluation under way

$$\text{BR}(\phi \rightarrow \eta'\gamma)/\text{BR}(\phi \rightarrow \eta\gamma) = [5.3 \pm 0.6] \times 10^{-3}$$

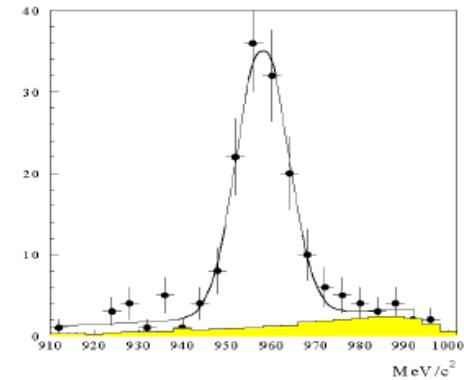
$$M_{\eta'} = [958.0 \pm 0.6] \text{ MeV}/c^2$$

$$\text{BR}(\phi \rightarrow \eta'\gamma) = [6.8 \pm 0.8] \times 10^{-5}$$

(PDG2000: BR = $[6.7 \pm 1.5] \times 10^{-5}$)

$$\Phi_{\text{mix}} = [40^{+1.7}_{-1.5}]^\circ \quad (\text{flavour basis})$$

$$= [-14.7^{+1.7}_{-1.5}]^\circ \quad (\text{singlet-octet basis})$$



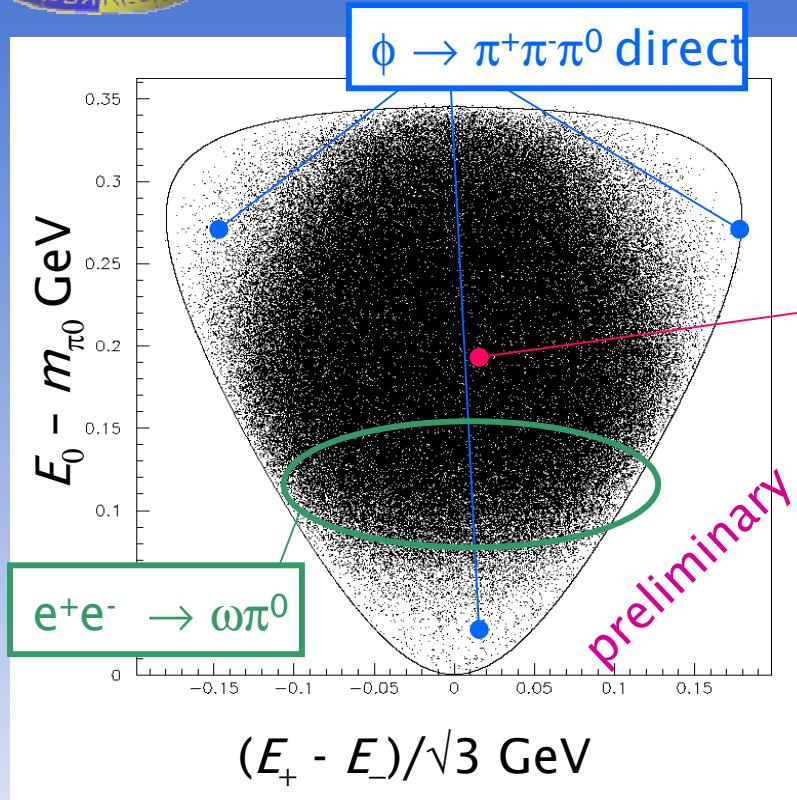
Systematics: precise evaluation under way

See Di Donato & Valeriani in parallel session A4



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

21



❖ 3 contributions to the Dalitz plot

- ❖ Fit free parameters:
 $M_\rho, \Delta M_\rho, \Gamma_\rho$ & decay amplitude
- ❖ Efficiency from Monte Carlo

	KLOE Fit (preliminary)	PDG
$M\rho^{+-} (\text{MeV}/c^2)$	775.3 ± 0.4	776.1 ± 1.0
$M\rho^0(\text{MeV}/c^2)$	773.0 ± 0.6	
$\Delta M^{+-} (\text{MeV}/c^2)$	0.4 ± 0.3	-
$\Gamma(\text{MeV}/c^2)$	149.1 ± 1.0	150.2 ± 0.8
$A(\text{dir.})/A(\rho\pi)$	$(8.5 \pm 0.5)\%$	$(-15 \div 11)\%$
$\phi(\text{dir.}) - \phi(\rho\pi)$	$(88 \pm 9)^\circ$	-

CPT test to 5×10^{-4}

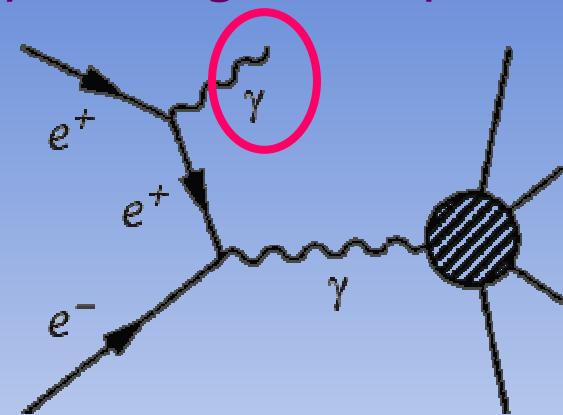


Hadronic cross section ($g-2$)

22

A dedicated energy scan is not foreseen but...

...the radiative return method can be used by looking at the process:
 $e^+e^- \rightarrow \text{hadrons} + \gamma$ (in the initial state, ISR)



$$d\sigma(e^+e^- \rightarrow \text{hadrons} + \gamma)/dQ^2 = \sigma(e^+e^- \rightarrow \text{hadrons}, Q^2) \times H(Q^2, \cos\theta_0)$$

Q^2 , the invariant mass of the hadronic system, varies continuously between:

$$4m_\pi^2 \leq Q^2 = (M_\phi^2 - 2 M_\phi \cdot E_\gamma) \leq m_\phi^2$$

61% of a_μ^{hadr} comes from the ρ : $e^+e^- \rightarrow \rho \rightarrow \pi^+\pi^-\gamma$
 $(0.28 \text{ GeV} < E_{\text{c.m.}} < 0.81 \text{ GeV})$



Hadronic cross section (g-2)

23

The radiative return method requires:

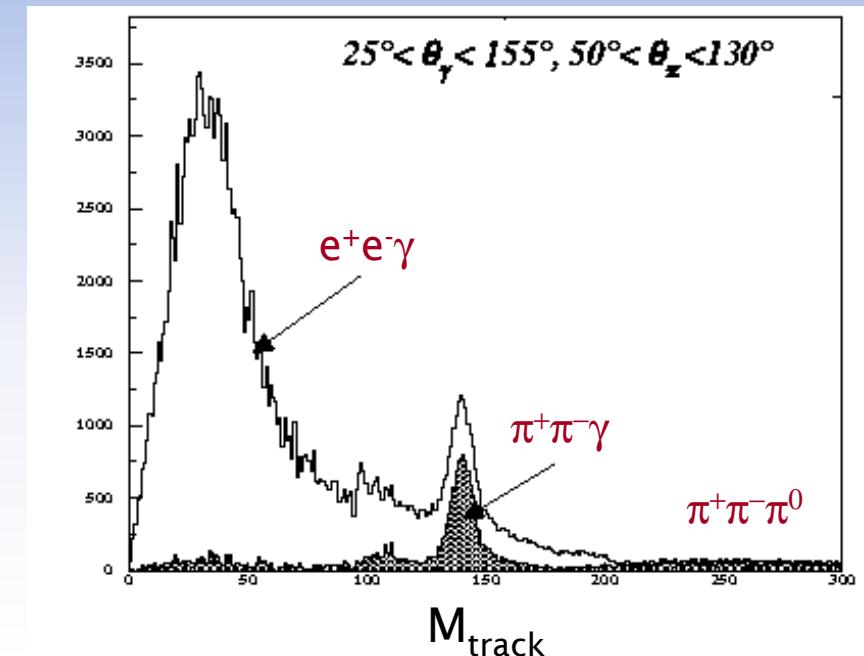
- ❖ Precise knowledge of **ISR**, including radiative corrections

EVA generator, S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459 (1999)

- ❖ Rejection of final state radiation (**FSR**) background

- ❖ Rejection of other experimental backgrounds:

radiative Bhabha, $\mu^+\mu^-\gamma$, $\phi \rightarrow \pi^+\pi^-\pi^0$

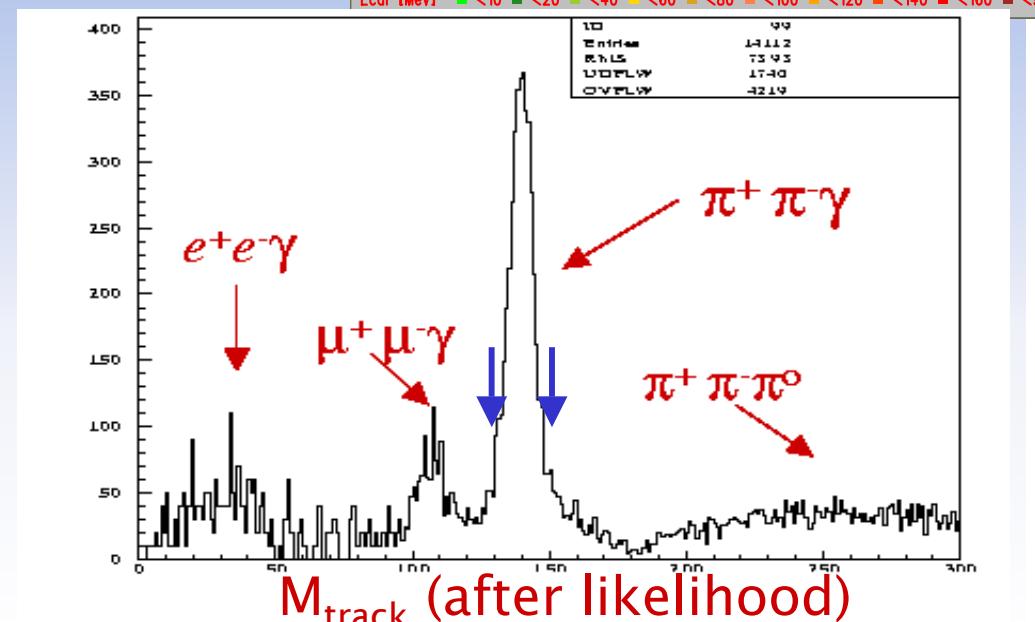
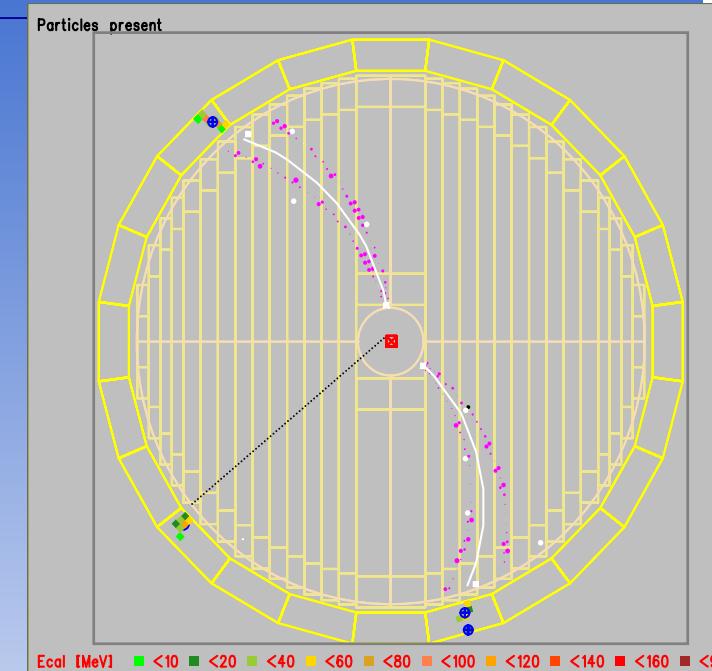




$\pi^+\pi^-\gamma$ identification

24

- ❖ Look for missing momentum in $\pi\pi$ tracks
 - ❖ Use drift chamber, $p_T > 200$ MeV/c
 - ❖ Estimate E_γ and θ_γ from $\pi\pi$ vertex and ϕ boost
- ❖ 2 fiducial volumes:
 - small angle: $\theta_\gamma < 21^\circ$; $\theta_\gamma > 169^\circ$
 - large angle: $60^\circ < \theta_\gamma < 120^\circ$
- ❖ Use calorimeter for π identification:
 - likelihood function using:
 - time-of-flight, shower profile
- ❖ 2 σ cut to reject $\pi^+\pi^-\pi^0$
- ❖ No need of γ information





$d\sigma_{\pi\pi} / dQ^2$

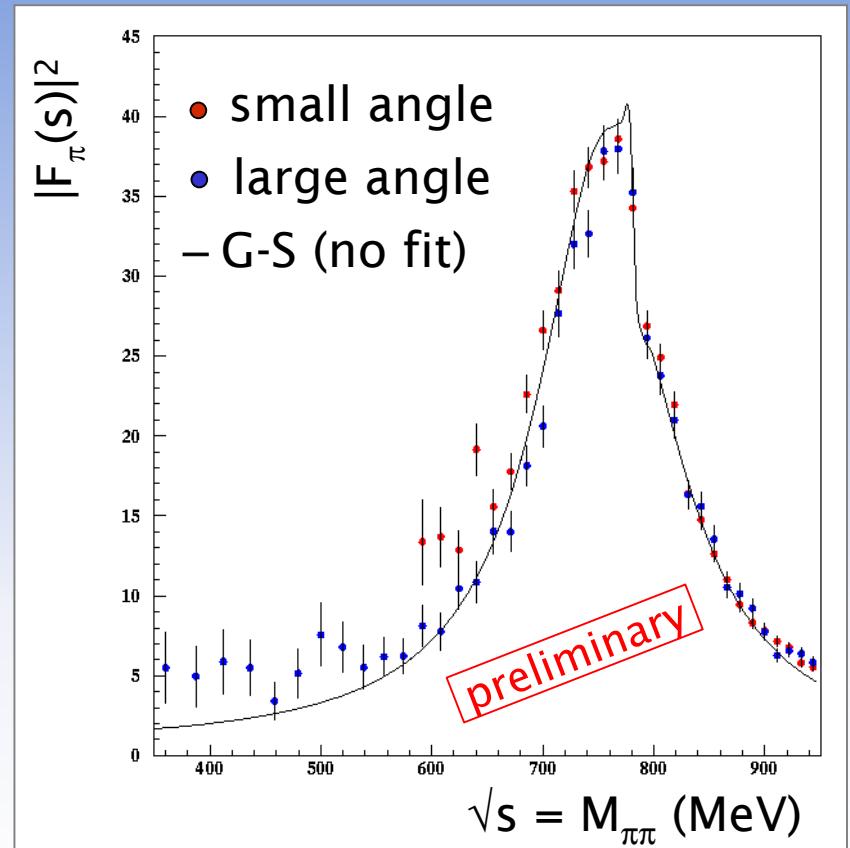
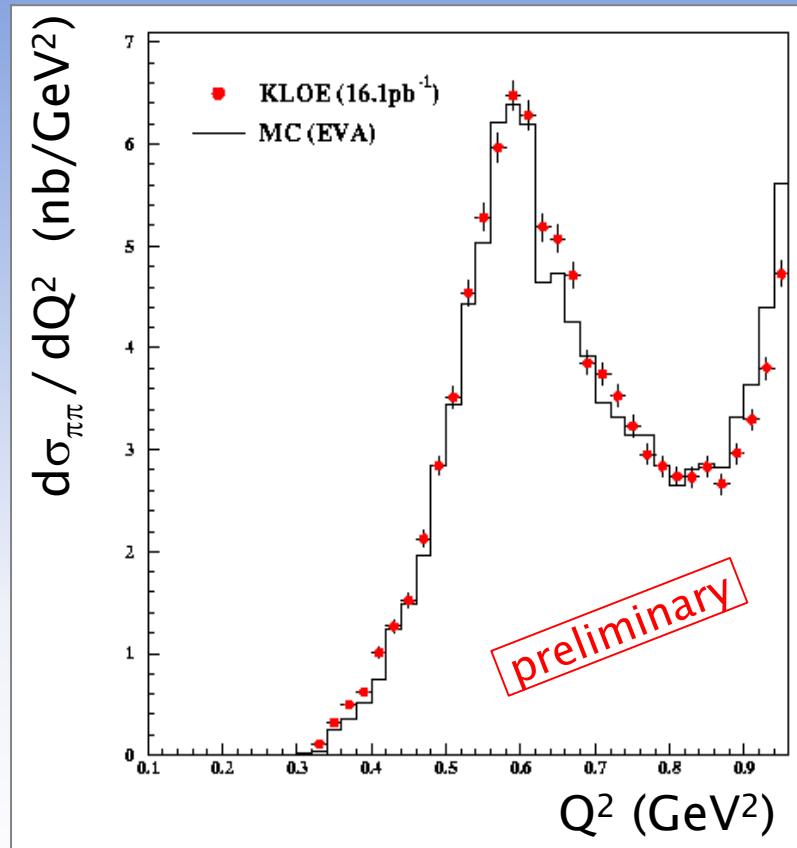
Evaluate hadronic cross section: $d\sigma/dQ^2 = (N^{\text{obs}} - N^{\text{bck}})/\Delta Q^2 \times (\varepsilon L)^{-1}$

Efficiencies:

- ❖ Acceptance from Monte Carlo
- ❖ vertex, trigger, likelihood from data
 $(\pi^+\pi^-\pi^0, \pi^+\pi^- \text{ and Bhabha})$

Luminosity:

- ❖ from large angle Bhabha (1%)





Conclusions

26

- ❖ DAΦNE accelerator luminosity is increasing
(200 pb⁻¹ expected by the end of 2001)
- ❖ Preliminary results show the good performance of the detector
- ❖ Several mature analyses:

$K_S \rightarrow \pi^+ \pi^-$; $BR(K_S \rightarrow \pi^+ \pi^-)/BR(K_S \rightarrow \pi^0 \pi^0)$

Radiative decays of the ϕ

- ❖ KLOE can measure $\sigma_{\pi\pi}$ with good accuracy, but...

The measurement requires thoroughful understanding of the detector acceptance and efficiencies

Complete theoretical calculations of the process are necessary with the corresponding radiative corrections

More fun & physics to come...