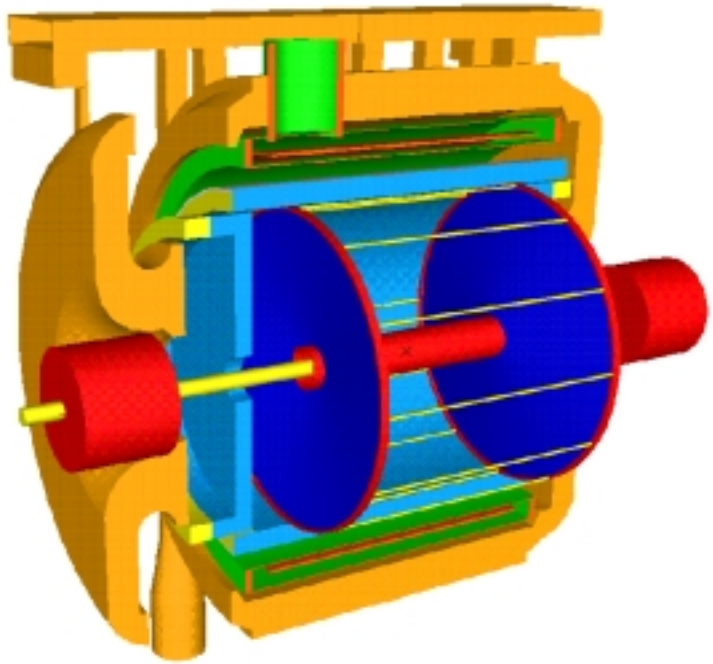


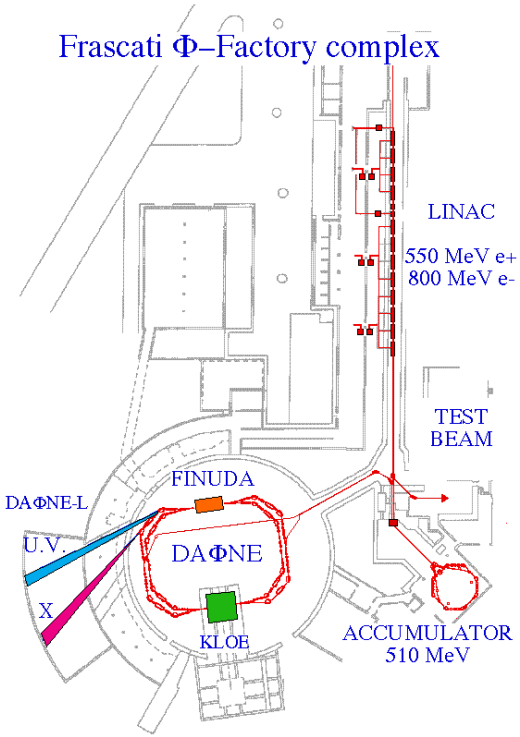
Recent results from the KLOE experiment at DAΦNE

M. Moulson (LNF), for the KLOE collaboration

Seventh Topical Seminar on the Legacy of LEP and SLC

Siena, 11 October 2001

Physics at a ϕ factory



$W = m_\phi = 1019$ MeV

$L_{design} = 5 \cdot 10^{32}$ cm^{-2} s^{-1}

$\phi \rightarrow K_S K_L$ (BR=33.8%)

$p_K = 110$ MeV

$\lambda_S, \lambda_L = 6$ mm, 3.5 m

$\phi \rightarrow K_S K_L$ provides monochromatic K_S, K_L beams in pure $J^{PC} = 1^{--}$ state

$K_S(K_L)$ tagged by observation of $K_L(K_S)$

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

KLOE can measure K_S and K_L *separately*
BR's for all 4 modes in the double ratio

Tagged K_S beam allows study of rare K_S decays

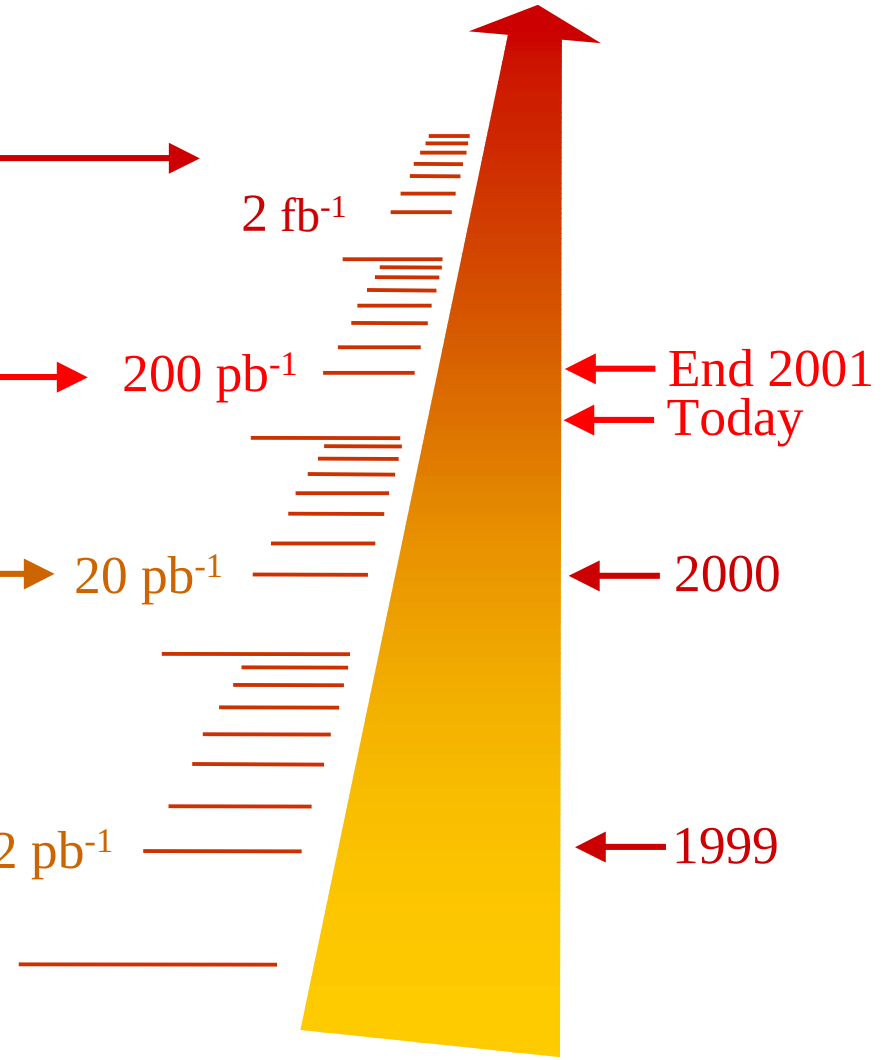
CP and *CPT* studies via quantum interferometry

The KLOE physics program

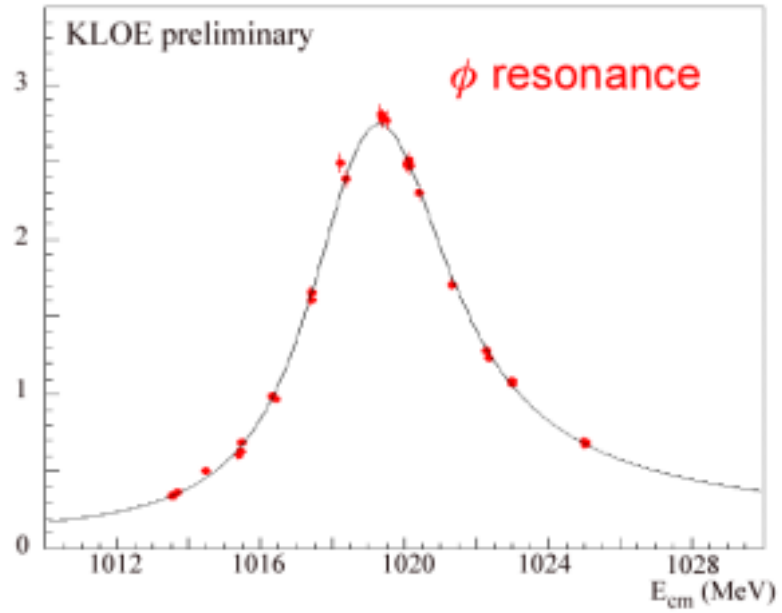
ε'/ε to $O(10^{-4})$ via double ratio
Semileptonic asymmetry (CPT test)
Interferometry

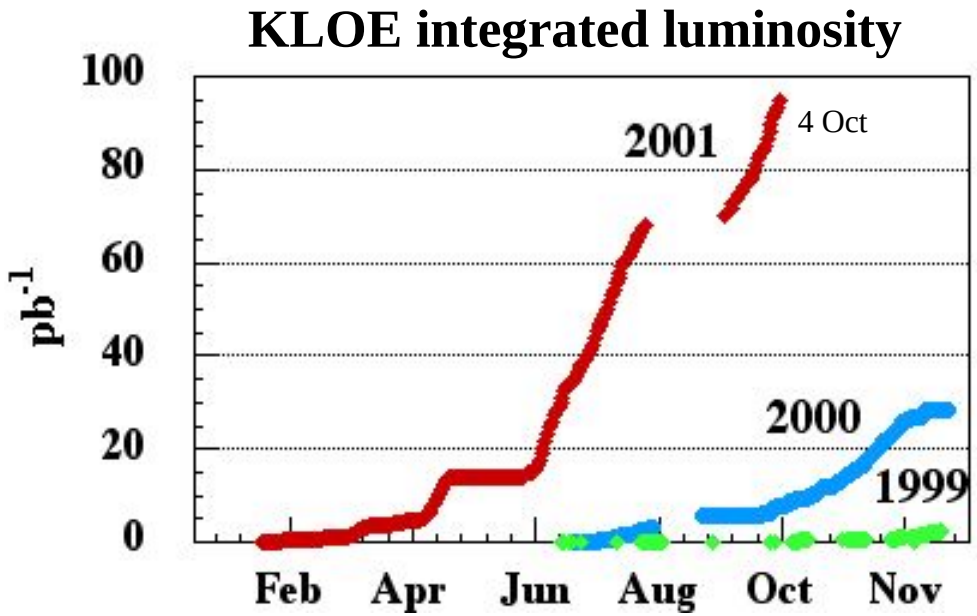
Close out K_S and ϕ physics
$K_S \to 3\pi^0$, other rare K_S decays
$K_L \to 2\pi$, $K_L \to \gamma\gamma$, form factors
$\sigma(e^+e^- \to \text{hadrons})$ to 1% (stat)

K_S physics
$\text{BR}(K_S \to \pi^+\pi^-)/\text{BR}(K_S \to \pi^0\pi^0)$
$\text{BR}(K_S \to \pi e \nu)$
ϕ radiative decays
$\phi \to f_0\gamma,\ a_0\gamma$
$\phi \to \eta'\gamma,\ \eta\gamma$



DAΦNE performance





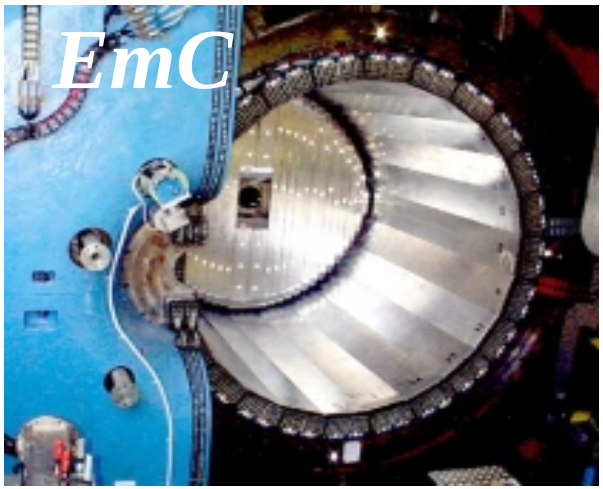
So far in 2001…

	Peak	Average
L (cm^{-2} s^{-1})	$3.5 \cdot 10^{31}$	$> 2 \cdot 10^{31}$
$\int_{\text{day}} L\,dt$ (pb^{-1})	1.9	> 0.8

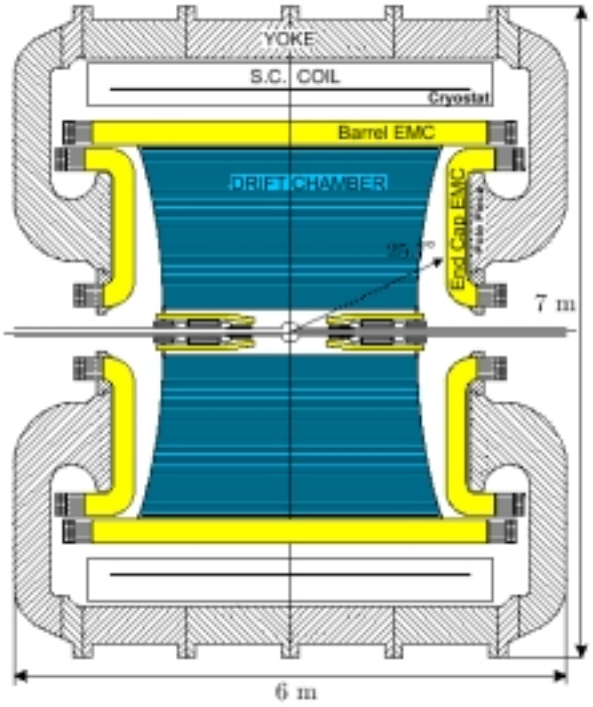
$$\int^{\text{today}} L\,dt = 115\ \text{pb}^{-1}$$

$$\int^{12/01} L\,dt \approx 200\ \text{pb}^{-1}$$

The KLOE detector



Lead/scintillating fiber
4880 PMTs
98% coverage of solid angle



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

σ_E/E 5.7% / $\sqrt{E}$(GeV)

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

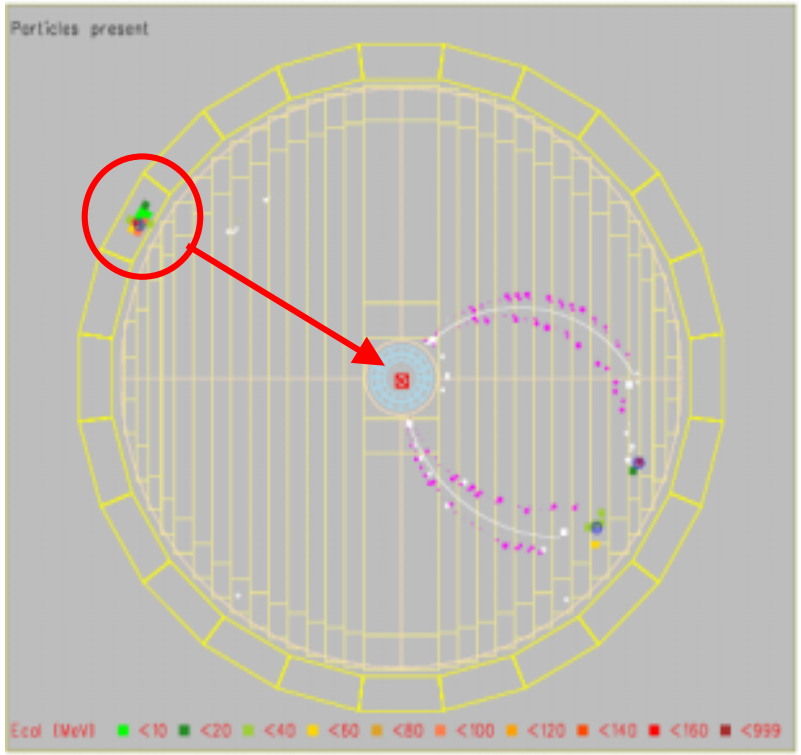
(finite bunch-length contribution subtracted)

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

σ_{xy} 150 μm

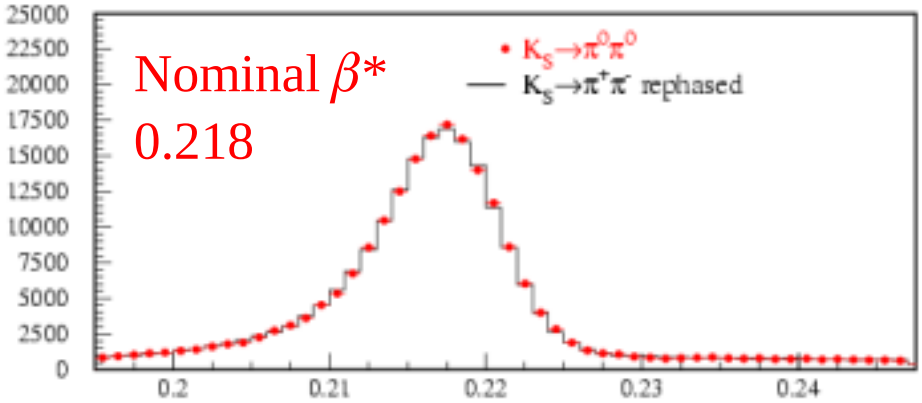
σ_z 2 mm

Tagging of K_S decays



17 pb^{-1} = 5.4M K_L crash candidates

TOF-identified K_L interaction in EmC
"K_L crash" provides clean K_S tag



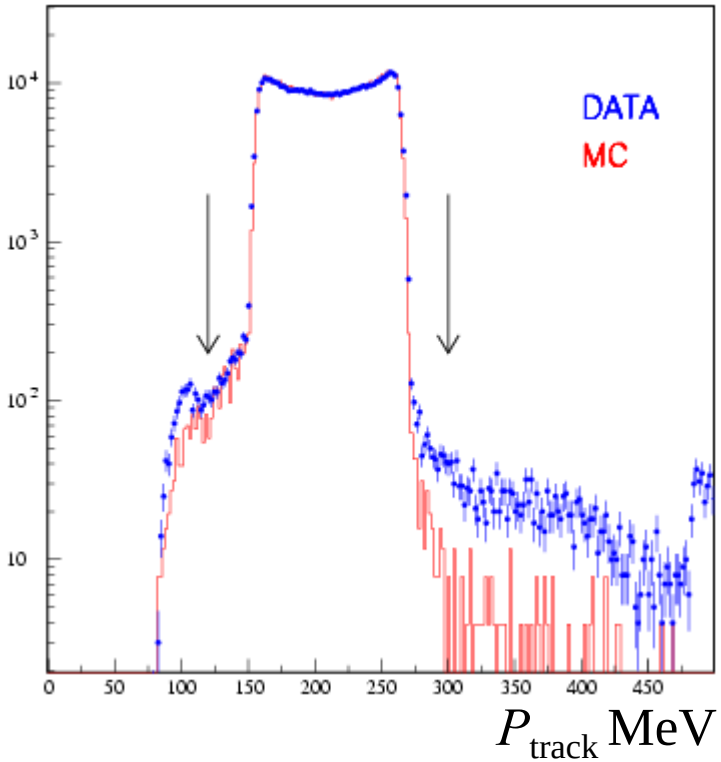
β^* = velocity of K_L in rest frame of ϕ

40% of time, K_L crash triggers by itself
Facilitates determination of trigger efficiency

$K_S \to \pi^+\pi^-$

K_L crash + 2 tracks from IP

Acceptance and loose p cuts—correction from MC



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

$$\varepsilon(\text{sel}\cdot\text{rec}) = (58.5 \pm 0.1)\ \%$$

Single-particle t_0 and trigger efficiencies from data:

$K_S \to \pi^+\pi^-$

also $K_L \to \pi e\nu$, $\phi \to \pi^+\pi^-\pi^0$

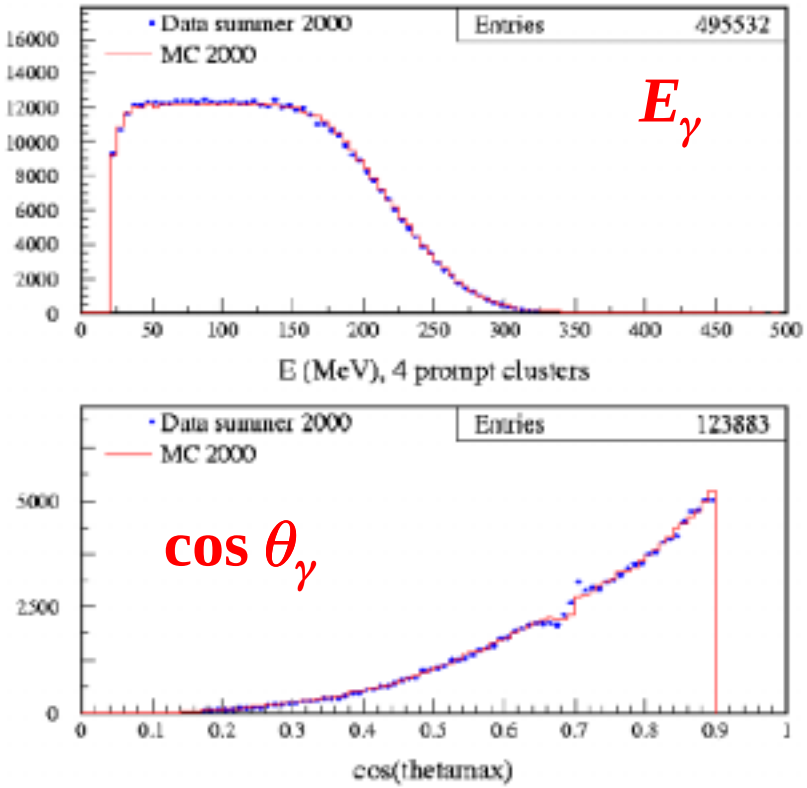
plugged into MC

$$\varepsilon(t_0\cdot\text{trig}) = (96.5 \pm 0.5)\ \%$$

$K_S \to \pi^0\pi^0$

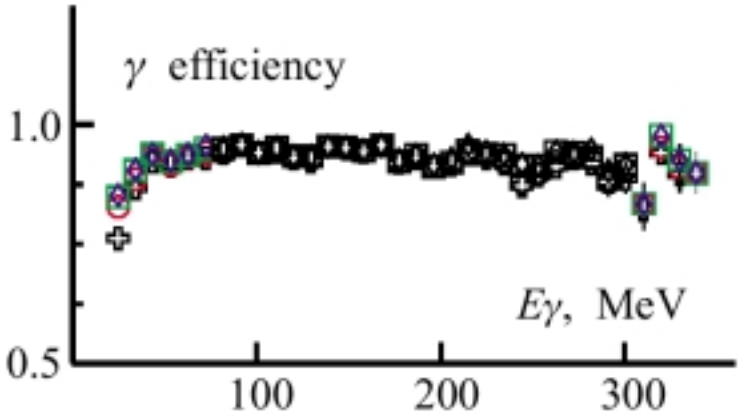
K_L crash + 4 prompt clusters

Acceptance (θ) and E cuts—correction from MC



Photon detection efficiency from data using $\phi \to \pi^+ \pi^- \pi^0$ events

$\varepsilon(\text{sel}\cdot\text{rec}) = (56.7 \pm 0.1)\%$



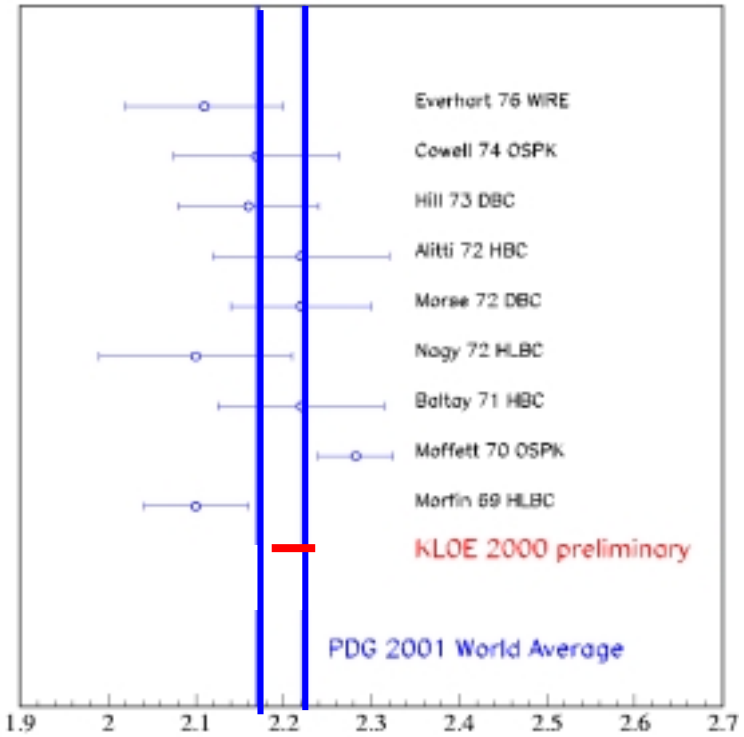
Trigger efficiency estimated by measuring probability of having 0,1 triggering clusters from data

$\varepsilon(t_0\cdot\text{trig}) = (99.69 \pm 0.03)\%$

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

KLOE 2000 preliminary (17 pb^{-1}) **$2.211 \pm 0.002_{stat} \pm 0.027_{syst}$**

PDG 2000 $2.197 \pm 0.026_{stat} \pm 0.013_{syst}$



Contribution to systematic error	%
$K_S \to \pi^0\pi^0$ selection*	1.0
Tag bias	0.5
$K_S \to \pi^+\pi^-$ trigger and t_0	0.5
$K_S \to \pi^+\pi^-$ selection	0.1
$K_S \to \pi^0\pi^0$ trigger	0.02
Overall systematic error	1.2

Work on $d\Gamma(K_S \to \pi^+\pi^-\gamma)/dE_\gamma$ in progress

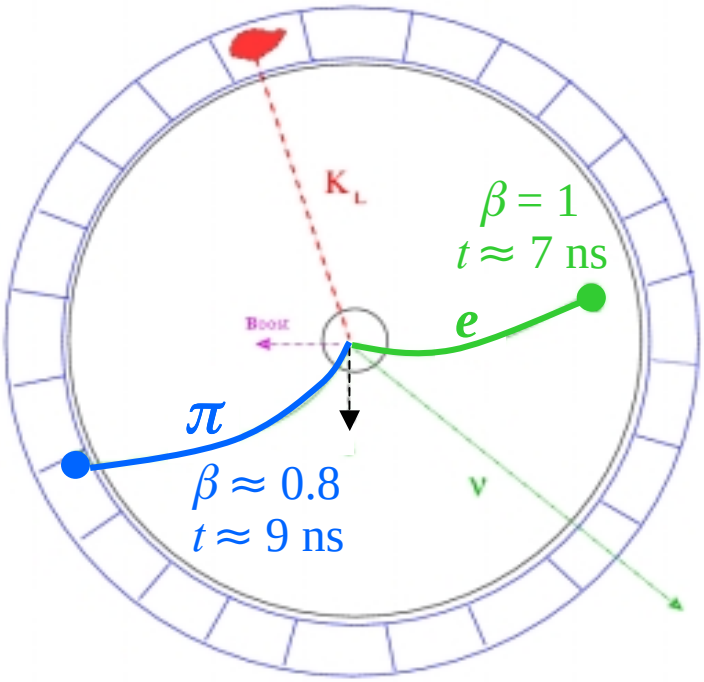
Analysis of $K_S \to \pi e \nu$ decays

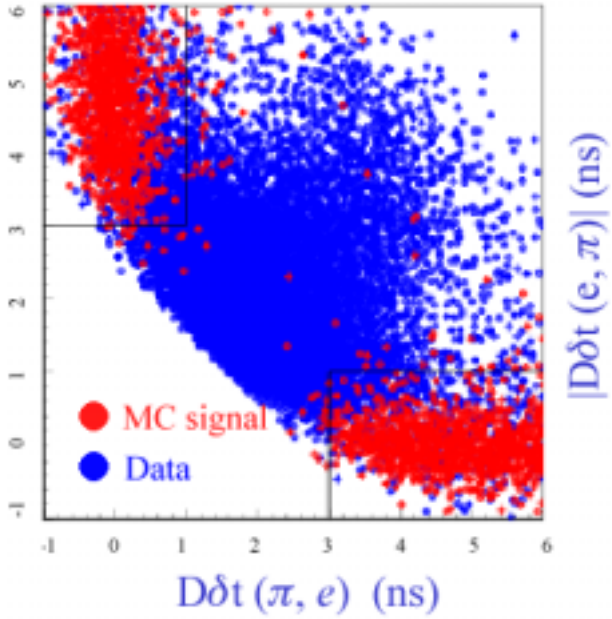
K_L crash + vertex at IP

2 tracks with associated EmC clusters

Preselection cuts on $M_{\pi\pi}$, P^*

Acceptance and selection efficiency from MC





π/e identification using time-of-flight

Cuts on $D\delta t(\pi, e)$, (e, π), (π, π), *e.g.*:

$D\delta t(\pi,e) \equiv [t_1 - t_2] - [T_1(\pi)^{exp} - T_2(e)^{exp}]$

Efficiency from $K_L \to \pi e \nu$ decays near origin

High-purity sample (> 99.7 %), isolable by kinematic cuts

Analysis of $K_S \to \pi e \nu$ decays

Single-particle t_0, track-cluster, and trigger efficiencies from data using:

$K_L \to \pi e \nu$ near origin

$\phi \to \pi^+\pi^-\pi^0, K_S \to \pi^+\pi^-$

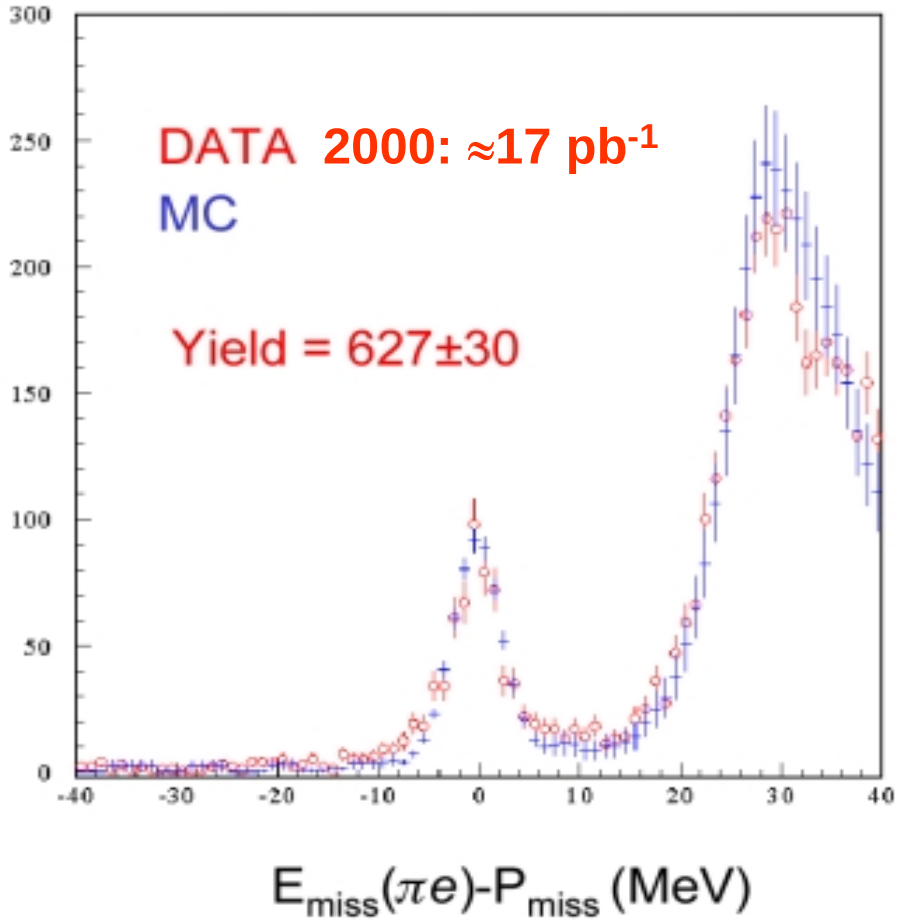
MC-weighted to get overall correction

Overall selection efficiency:

$(21.4 \pm 0.2_{stat} \pm 0.7_{syst})\%$

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

Normalization to $K_S \to \pi^+\pi^-$ decays



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

KLOE 2000 preliminary (17 pb^{-1})	**$(6.69 \pm 0.40) \cdot 10^{-4}$**
CMD-2 1999, 75 ± 13 evts.	$(7.2 \pm 1.4) \cdot 10^{-4}$
$\Gamma(K_S \to \pi e \nu) = \Gamma(K_L \to \pi e \nu)$	$(6.70 \pm 0.07) \cdot 10^{-4}$

Correction	%
Preselection	$62.4 \pm 0.3_{stat} \pm 2.0_{syst}$
Acceptance	$51.1 \pm 0.2_{stat}$
Track topology cuts	$95.8 \pm 0.1_{stat} \pm 0.3_{syst}$
Cluster $\cdot\, t_0 \cdot$ trigger	$85.3 \pm 0.4_{stat} \pm 0.5_{syst}$
TOF selection	$82.0 \pm 0.7_{stat}$
Tag bias	$97.7 \pm 0.4_{stat} \pm 0.5_{syst}$

$\phi \to \eta'\gamma, \eta\gamma$

Precise measurements of BR($\phi \to \eta'\gamma$) and BR($\phi \to \eta\gamma$) provide for:

- Probe of hidden strangeness and gluonium content of η'
- Determination of $\eta - \eta'$ mixing angle

$$\phi \to \eta'\gamma \to \pi^+\pi^-\eta\gamma$$
$$\to \pi^+\pi^-3\gamma$$

$$\phi \to \eta\gamma \to \pi^+\pi^-\pi^0\gamma$$
$$\to \pi^+\pi^-3\gamma$$

Event selection

3 prompt clusters with $E > 7$ MeV, $\theta > 21°$

Vertex near IP

Preliminary kinematic fit

Constraints: conservation of total E, **p**; $\beta = 1$ for each γ

Simple kinematic cuts to eliminate background:

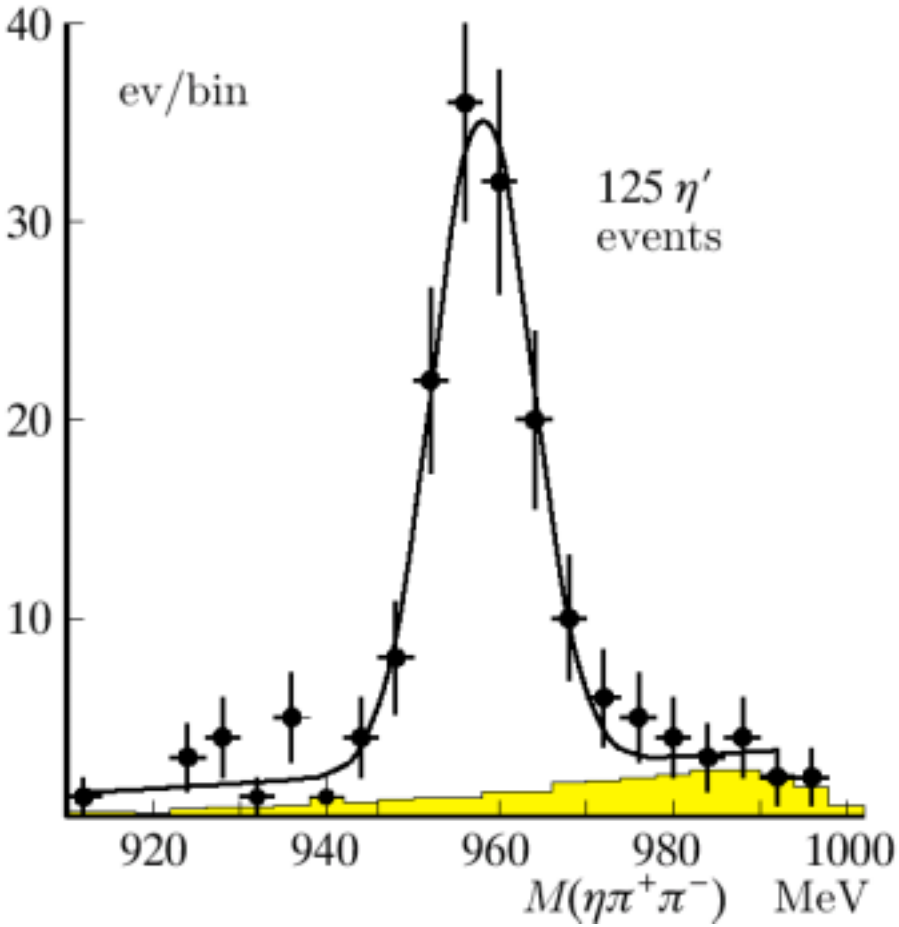
$\phi \to \pi^+\pi^-\pi^0$ with extra γ

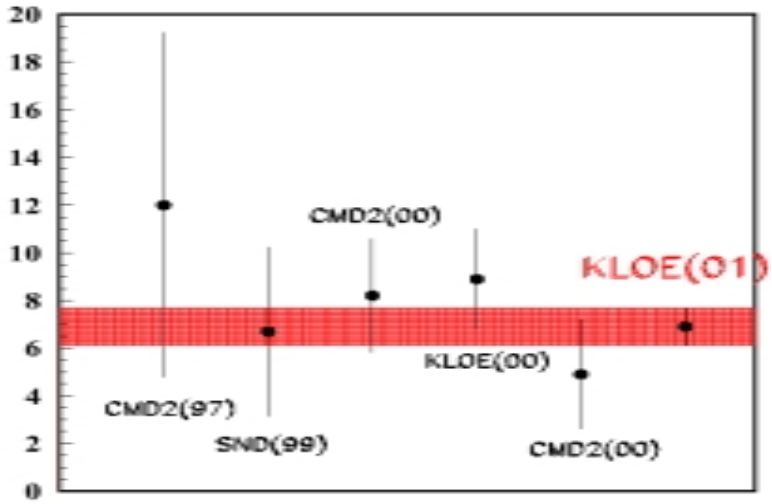
$\phi \to K_S K_L \to \pi^+\pi^-\pi^0\pi^0$ with γ lost

Only surviving background to $\phi \to \eta'\gamma$ (at level of MC statistics) is from $\phi \to \eta\gamma$

BR($\phi \to \eta'\gamma$) *and* BR($\phi \to \eta\gamma$)

KLOE 2000 preliminary (17 pb^{-1})





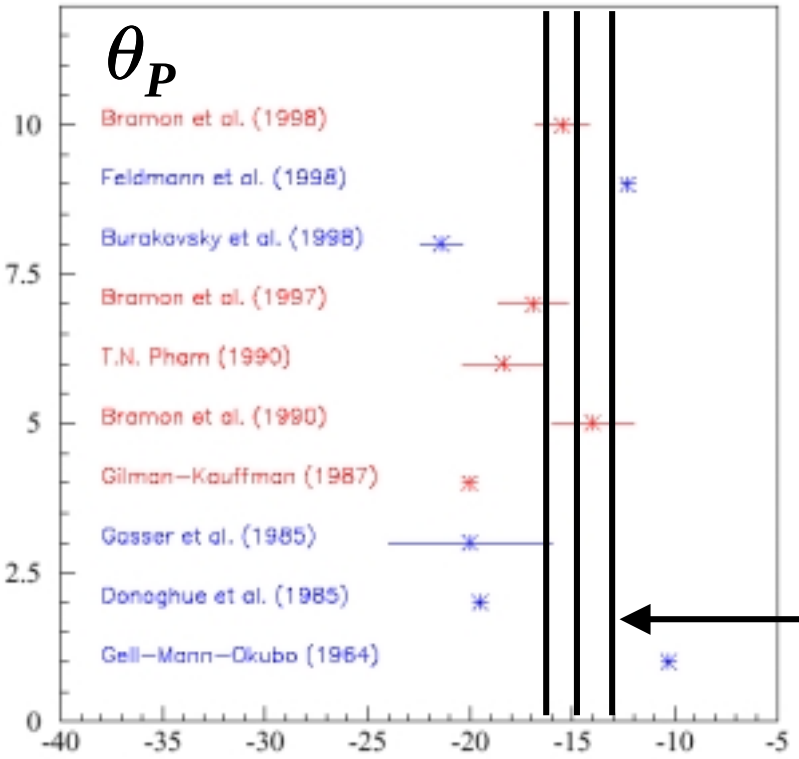
BR($\phi \to \eta'\gamma$)/BR($\phi \to \eta\gamma$) =
$(5.3 \pm 0.5_{stat} \pm 0.3_{syst}) \cdot 10^{-3}$

BR($\phi \to \eta'\gamma$) = with PDG value for $\phi \to \eta\gamma$
$(6.8 \pm 0.6_{stat} \pm 0.5_{syst}) \cdot 10^{-5}$

Disfavors significant gluonium content for η'

BR($\phi \to \eta'\gamma$) *and* BR($\phi \to \eta\gamma$)

KLOE 2000 preliminary (17 pb^{-1})



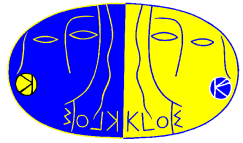
Measurement of BR($\phi \to \eta'\gamma$)/BR($\phi \to \eta\gamma$) gives most accurate determination of pseudoscalar mixing angle to date:

$$\varphi_P = 40.0^{+1.7}_{-1.5} \quad \text{(flavor basis)}$$

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

- Theoretical predictions
- Phenomenological analyses

$\phi \to \pi^0\pi^0\gamma\ (f_0\gamma)$ *and* $\phi \to \eta\pi^0\gamma\ (a_0\gamma)$



Composition of f_0 and a_0 mesons uncertain

Precise measurements of BR($\phi \to f_0\gamma$) and BR($\phi \to a_0\gamma$) may distinguish between various models: $q\bar{q}q\bar{q}$ state, $K\bar{K}$ molecule, ordinary $q\bar{q}$ meson

Detect 5γ final states $\left\{ \begin{array}{l} \phi \to f_0\gamma \to \pi^0\pi^0\gamma \to 5\gamma \\ \phi \to a_0\gamma \to \eta\pi^0\gamma \to 5\gamma \end{array} \right.$

Summary of backgrounds:

Resonant:

$\phi \to \rho^0\pi^0 \to \pi^0\pi^0\gamma$ S/B = 3.7

$\phi \to \rho^0\pi^0 \to \eta\pi^0\gamma$ S/B = 5.3

Continuum:

$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ S/B = 0.6

$e^+e^- \to \omega\pi^0 \to \eta\pi^0\gamma$ S/B = 70

Misreconstructed, 3γ

$\phi \to \pi^0\gamma$

$\phi \to \eta\gamma \to \gamma\gamma\gamma$

$e^+e^- \to \gamma\gamma(\gamma)$

Misreconstructed, 7γ

$\phi \to \eta\gamma \to \pi^0\pi^0\gamma$

$\phi \to \pi^0\pi^0\gamma\ (f_0\gamma)$ and $\phi \to \eta\pi^0\gamma\ (a_0\gamma)$

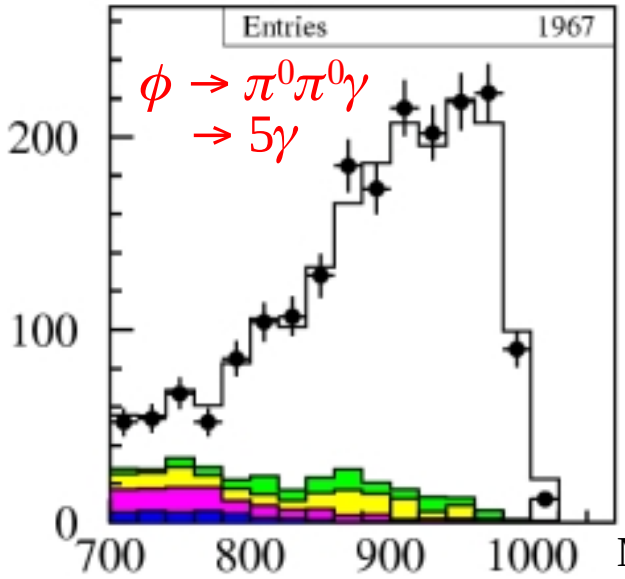
KLOE 2000 preliminary (17 pb^{-1})

$\phi \to S_{I=0}\gamma \to \pi^0\pi^0\gamma$ BR($M_{\pi\pi}$ > 700 MeV) = $(7.9 \pm 0.2_{stat}) \cdot 10^{-5}$

$\phi \to a_0\gamma \to \eta\pi^0\gamma$ BR = $(5.8 \pm 0.5_{stat}) \cdot 10^{-5}$

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

Favorable comparison with prediction for f_0, a_0 compact $q\bar{q}$ or $q\bar{q}q\bar{q}$ states with significant virtual $K\bar{K}$ component F. Close and A. Kirk, PLB515,13(2001)



$M(\pi^0\pi^0)$

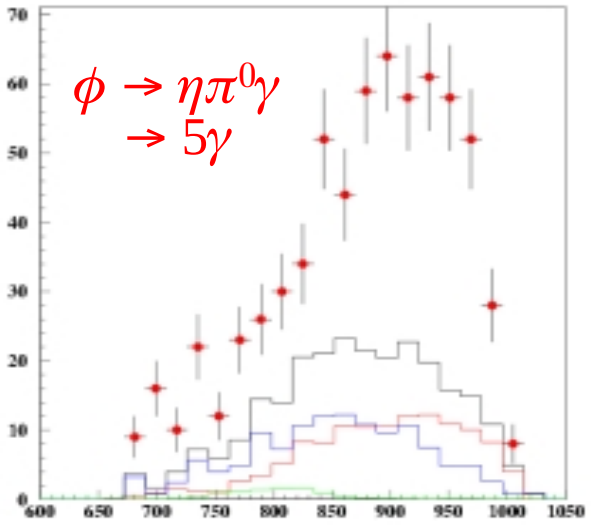
Backgrounds:

$e^+e^- \to \omega\pi^0$

$\phi \to \eta\gamma$

$\phi \to \rho\pi^0$

$\phi \to a_0\gamma$



$M(\eta\pi^0)$

Backgrounds:

$\phi \to \pi^0\pi^0\gamma$

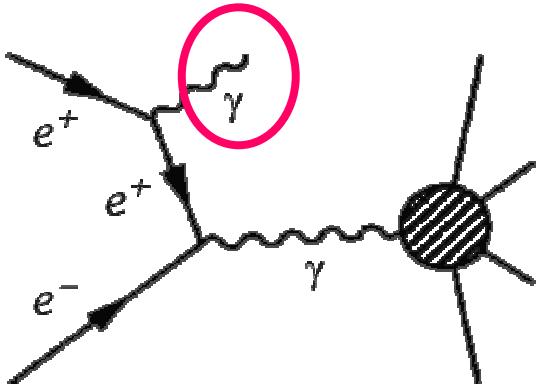
$e^+e^- \to \omega\pi^0$

$\phi \to \eta\gamma$

Total

$\sigma(e^+e^- \to hadrons)$

KLOE can measure $d\sigma/dM_{\pi\pi}^2(e^+e^- \to hadrons)$ for $2m_\pi < M_{\pi\pi} < m_\phi$ using $e^+e^- \to \pi^+\pi^-\gamma$ with γ radiated in initial state (ISR)



~70% of $\delta a_\mu^{\text{hadr}}$ $(5000 \cdot 10^{-11})$ comes from this interval in $M_{\pi\pi}$

Precise knowledge of ISR and FSR required, including *all* radiative corrections

- FSR suppressed with acceptance cuts (as opposed to included in fit to $dN/dM_{\pi\pi}^2$)
- Exclusive measurement of $\pi^+\pi^-\gamma$ final state (multi-photon final state excluded)

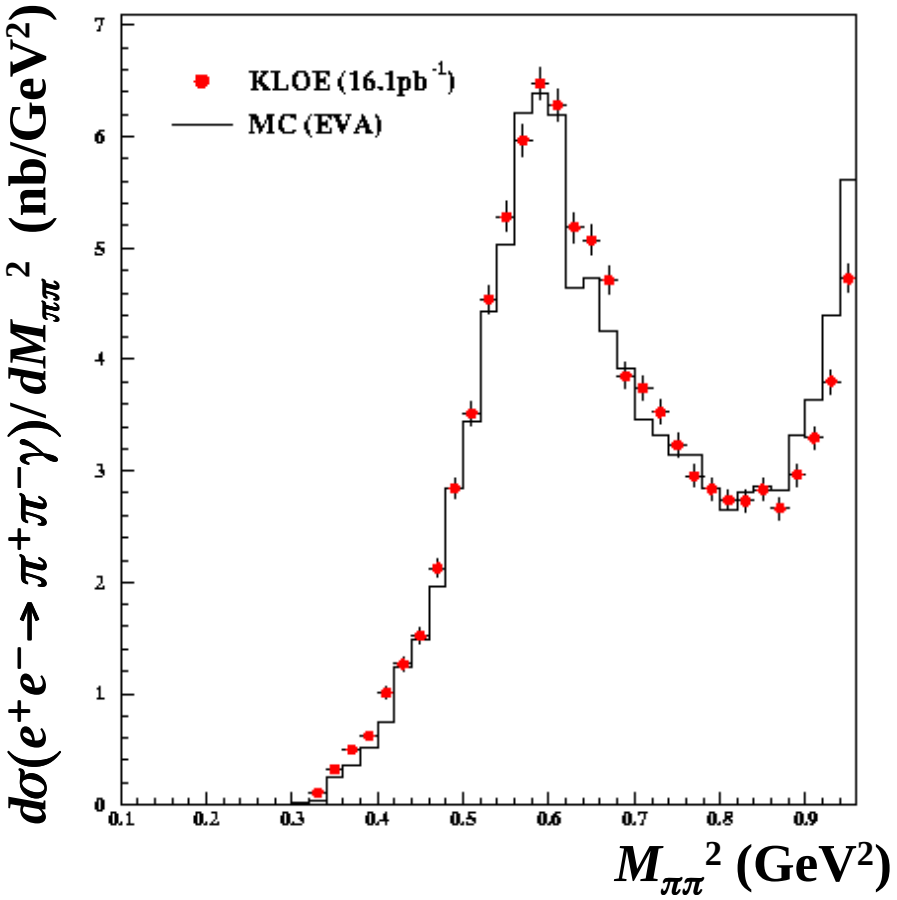
Measurement is delicate, but KLOE can make unique contributions:

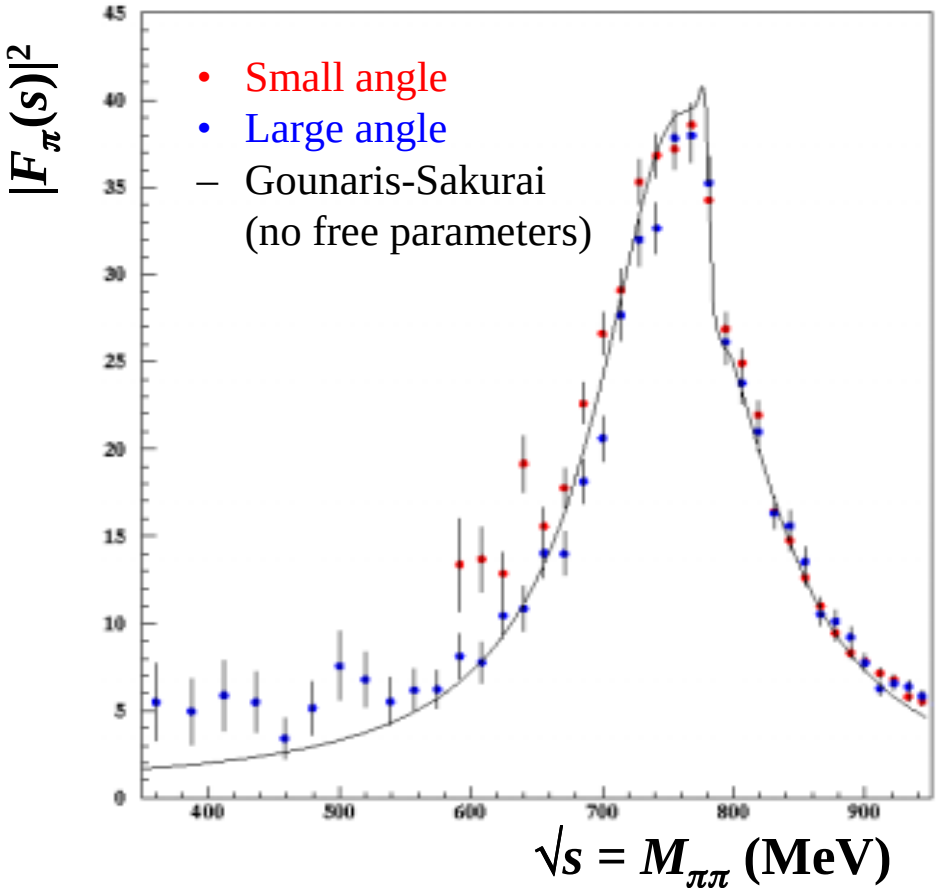
- Confirm and complement results from $e^+e^- \to \pi^+\pi^-$ and τ data,
  - with different systematics
- Measure $d\sigma/dM_{\pi\pi}^2$ for low $M_{\pi\pi}$ (< 0.6 GeV)

$\sigma(e^+e^- \to hadrons)$

KLOE 2000 preliminary (16.1 pb^{-1})

Statistical errors
Experimental systematics
Theoretical systematics
} few %





Conclusions

DAΦNE performance has improved considerably during the first two years of KLOE data taking

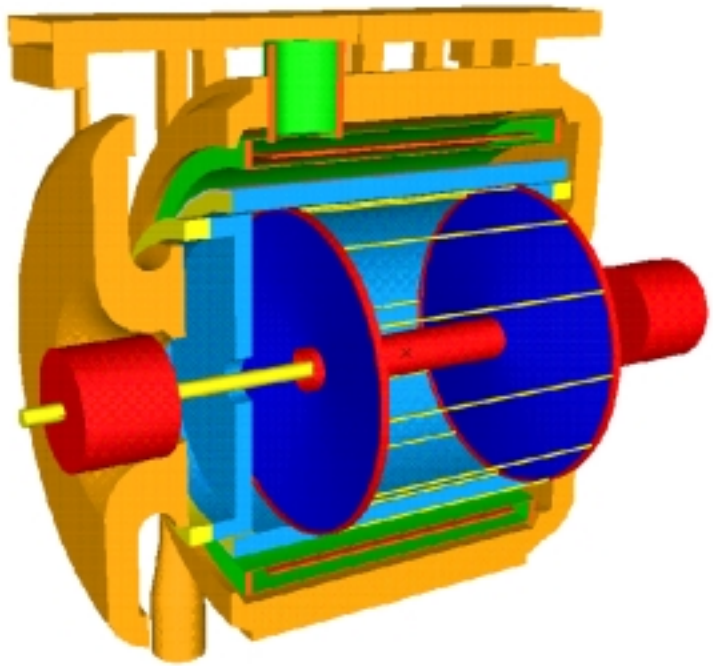
First ~20 pb^{-1} of KLOE data have yielded results on:

- BR($K_S \to \pi^+\pi^-$)/BR($K_S \to \pi^0\pi^0$), BR($K_S \to \pi e \nu$)
- $\phi \to f_0\gamma \to \pi^0\pi^0\gamma$ and $\phi \to a_0\gamma \to \eta\pi^0\gamma$ decays

200 pb^{-1} expected by end of 2001 will permit:

- Complete and definitive results for 20 pb^{-1} physics
- $K_S \to 3\pi^0$, $K_S \to \gamma\gamma$, $K_S \to \pi^+\pi^-\gamma$ decays
- $K_L \to 2\pi$, $K_L \to \gamma\gamma$ decays
- Charged kaon decays
- $\sigma(e^+e^-$ hadrons) to 1% statistical error

Spares and originals



Results to present

Physics with 20 pb^{-1}

K_S decays

$\mathrm{BR}(K_S \to \pi^+\pi^-)/\mathrm{BR}(K_S \to \pi^0\pi^0)$

$\mathrm{BR}(K_S \to \pi e \nu)$

Radiative decays of the ϕ

$\phi \to f_0\gamma,\ a_0\gamma$

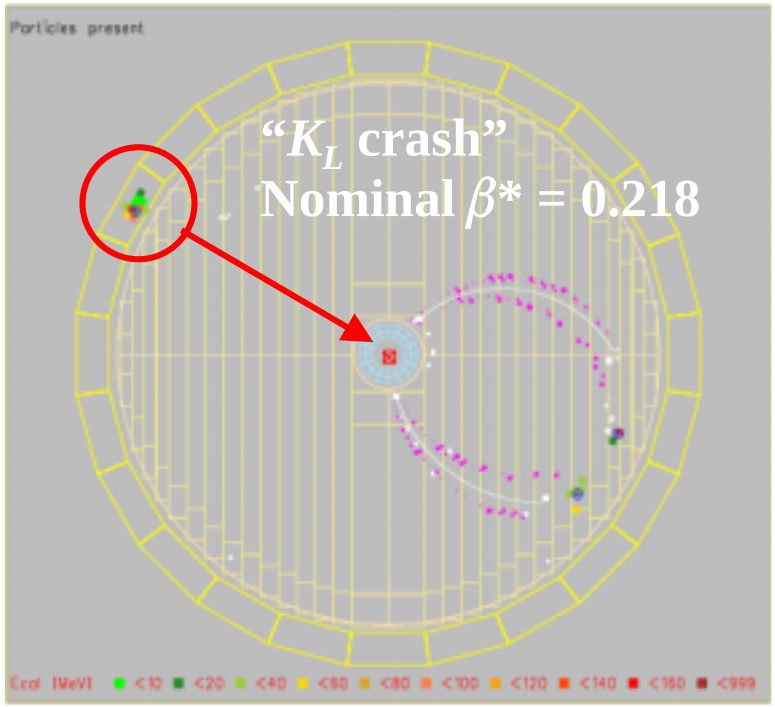
$\phi \to \eta'\gamma,\ \eta\gamma$

Physics with 200 pb^{-1}

$\sigma(e^+e^- \to \mathrm{hadrons})$

Tagging of K_S decays

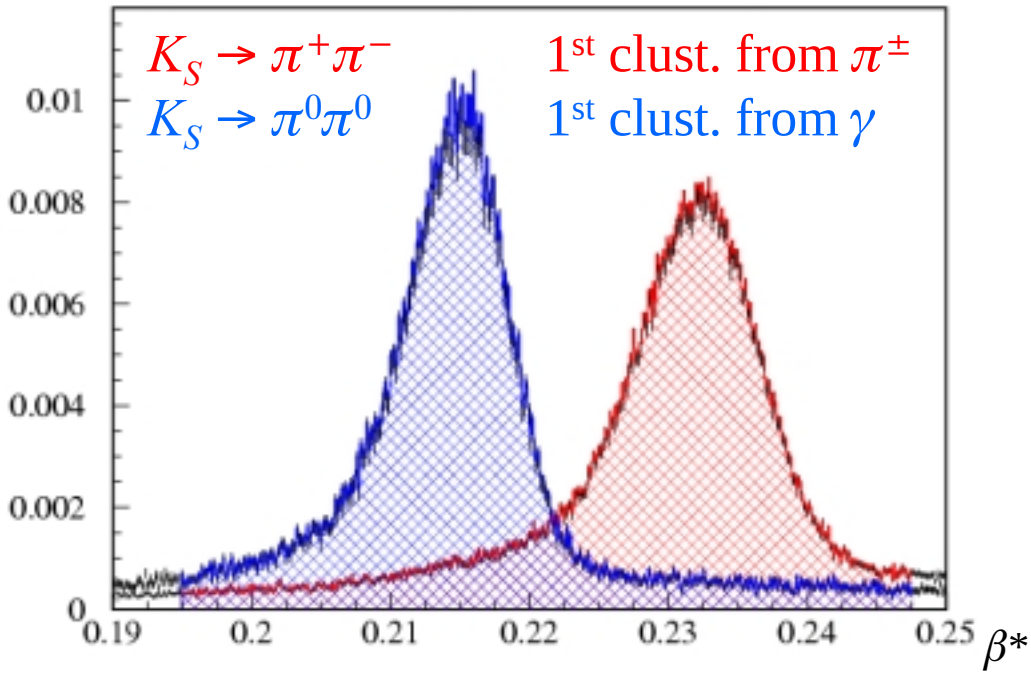
TOF-identified K_L interaction in EmC provides clean K_S tag



β^* = velocity of K_L in rest frame of ϕ

$0.1950 < \beta^* < 0.2475$

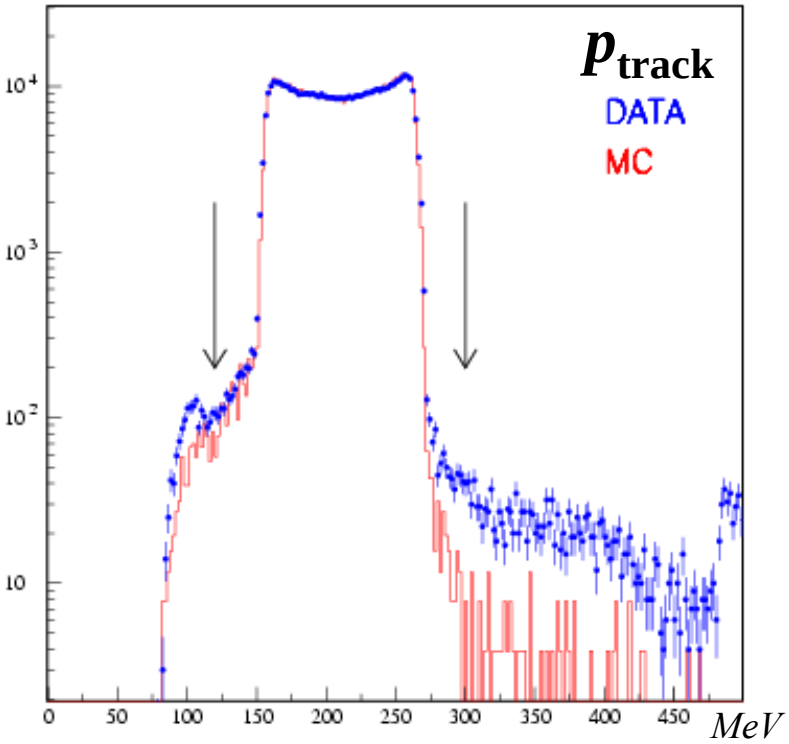
Event t_0 fixed by subtracting β=1 TOF from earliest cluster time and synchronizing with bunch crossing frequency



40% of time, K_L crash triggers by itself

Allows determination of trigger efficiency

$K_S \to \pi^+\pi^-$

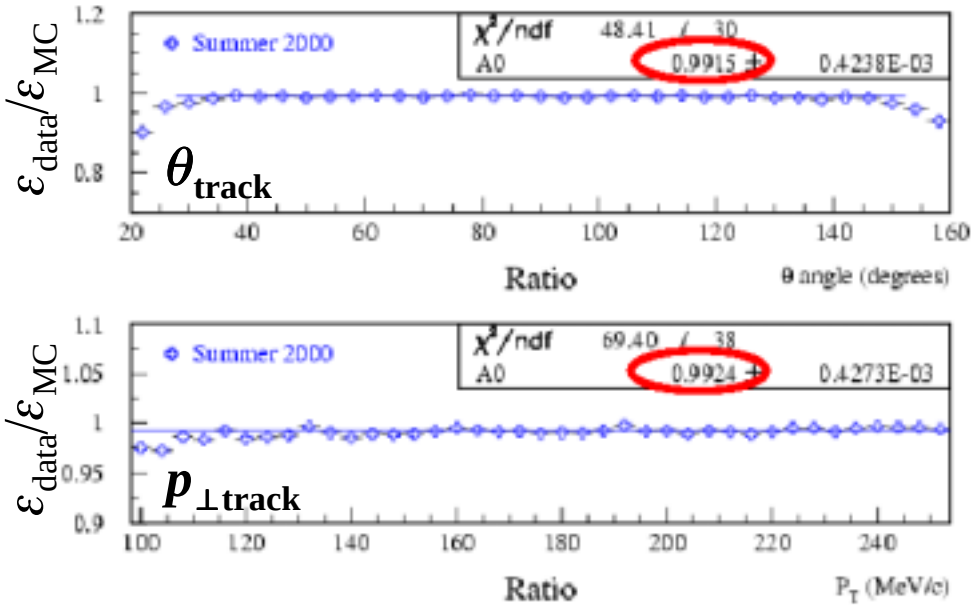


K_L crash + 2 tracks from IP

Acceptance and loose p cuts, correction from MC

$\varepsilon(\text{sel}\cdot\text{rec}) = (58.5 \pm 0.1)\ \%$

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



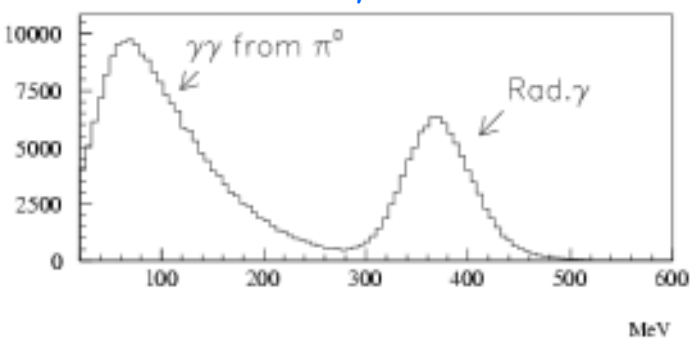
Single-particle t_0 and trigger efficiencies from $K_S \to \pi^+\pi^-$ data (and $K_L \to \pi e\nu$, $\phi \to \pi^+\pi^-\pi^0$), plugged into MC

$\varepsilon(t_0\cdot\text{trig}) = (96.5 \pm 0.5)\ \%$

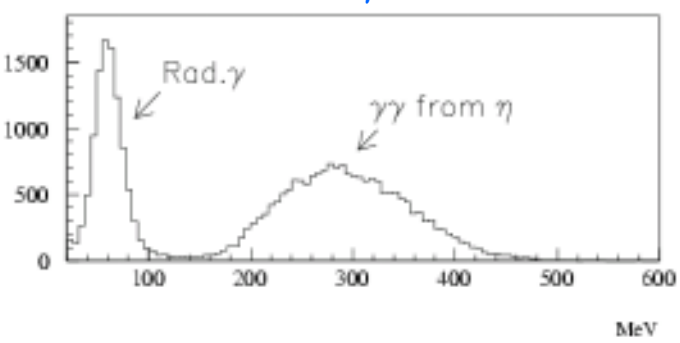
Discrimination of $\phi \to \eta'\gamma$ from $\phi \to \eta\gamma$

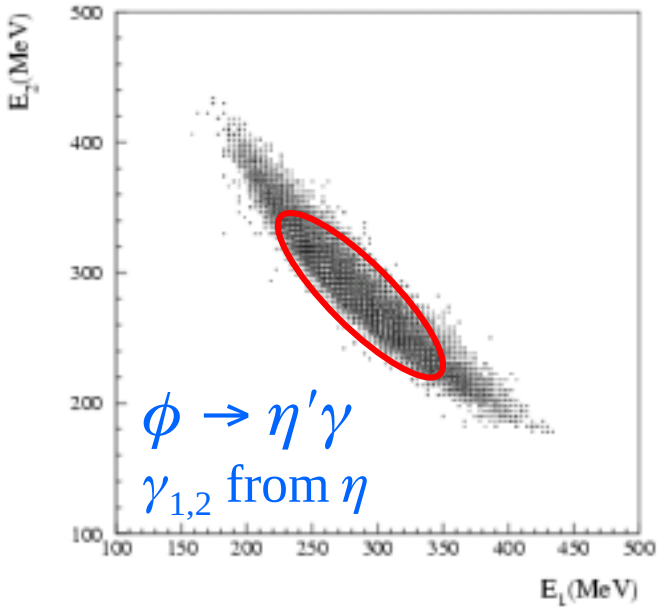
Assignment of radiative γ easy and provides excellent η'/η discrimination

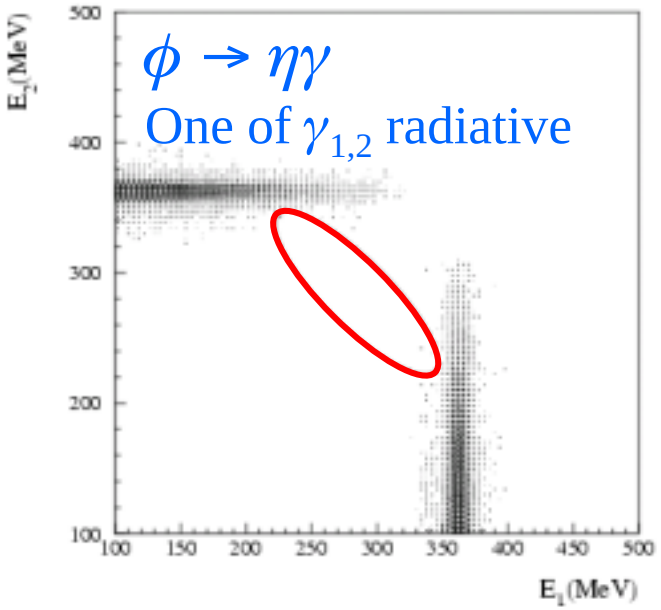
$\phi \to \eta\gamma$ E_γ = 363 MeV



$\phi \to \eta'\gamma$ E_γ = 60 MeV







Cut in E_1 vs E_2 for two hardest γ's selects $\eta'\gamma$ events

$\varepsilon(\phi \to \eta'\gamma) = 23.0\%$

Cut on E_{rad} selects $\eta\gamma$ events

$\varepsilon(\phi \to \eta\gamma) = 37.6\%$

Analysis of $\phi \to \pi^0\pi^0\gamma$ and $\phi \to \eta\pi^0\gamma$

Event selection

5 prompt clusters with $E > 7$ MeV, $\theta > 21°$

Preliminary kinematic fit

Variables: (x, y, z, E, t) for each γ; beam energies; (x, y, z) of IP

Constraints: conservation of total E, $\mathbf{p}$; $\beta = 1$ for each γ

Kinematic cuts: masses of intermediate particles, ψ angle

Best γ pairing obtained for each topology

Final kinematic fit applied in each case

Further constraints on π^0 and η masses

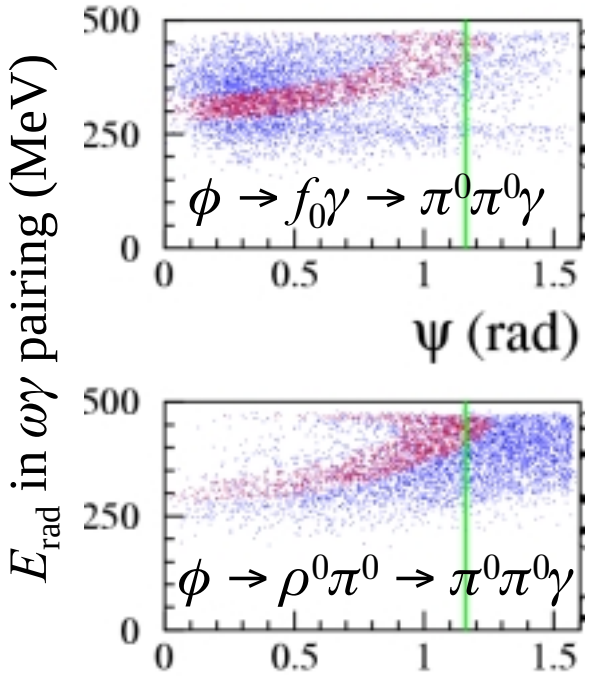
Signal efficiencies:

$\varepsilon(\phi \to \pi^0\pi^0\gamma) = 39.7\%$, $\varepsilon(\phi \to \eta\pi^0\gamma) = 27.2\%$

KLOE preliminary value for σ_ϕ used to evaluate BR

$3.17 \pm 0.01_{stat} \pm 0.14_{syst}$ μb from $\phi \to \eta\gamma \to \gamma\gamma\gamma$

Angle of γ emission in $\pi^0\pi^0$ CM, evaluated in $\omega\pi^0$ pairing



Analysis of $\sigma(e^+e^- \to hadrons)$

Event selection

Vertex near IP, γ not directly observed

EmC e/π discrimination to reject Bhabha events

Likelihood function using TOF, shower profile

M_{track} cut

Mass needed by tracks for zero missing mass

Acceptance cuts (correction from MC)

Tracks: $p_\perp > 200$ MeV, $55° < \theta < 125°$

Two fiducial volumes for γ ($E_\gamma > 10$ MeV)

Small angle: $\theta < 21°$; $\theta > 169°$

Large angle: $60° < \theta < 120°$

Vertex, trigger, selection efficiencies from data

$\pi^+\pi^-\pi^0$, $\pi^+\pi^-\gamma$, and Bhabha events

Luminosity (~1% systematic error)

Bhabha events with $25° < \theta < 155°$