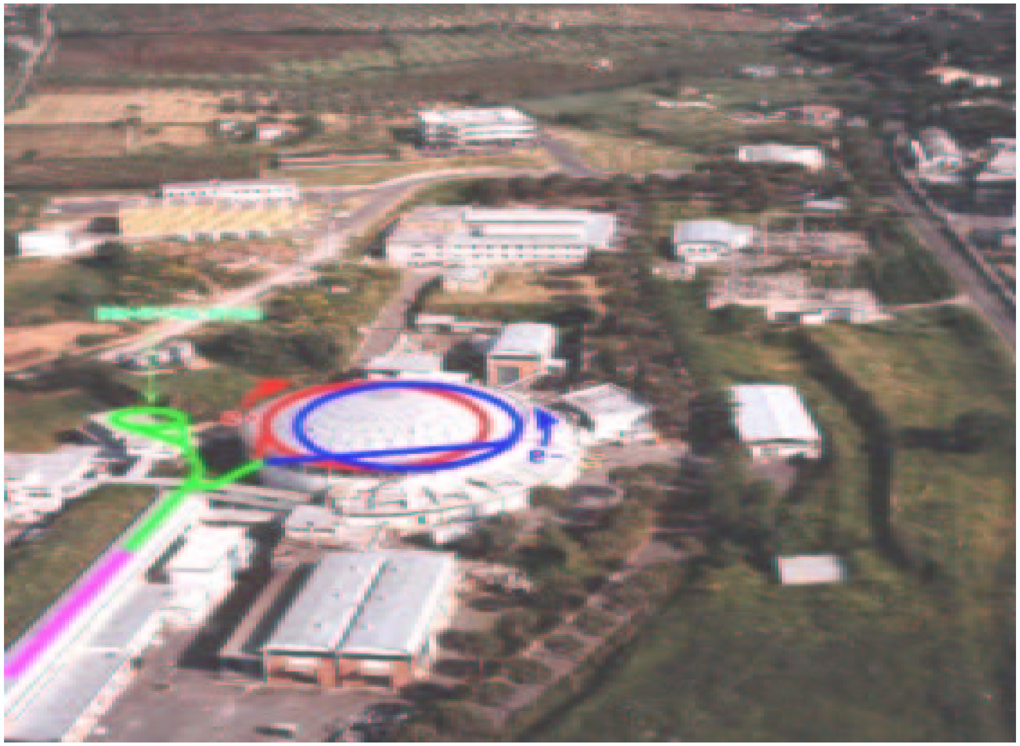
Recent results from KLOE



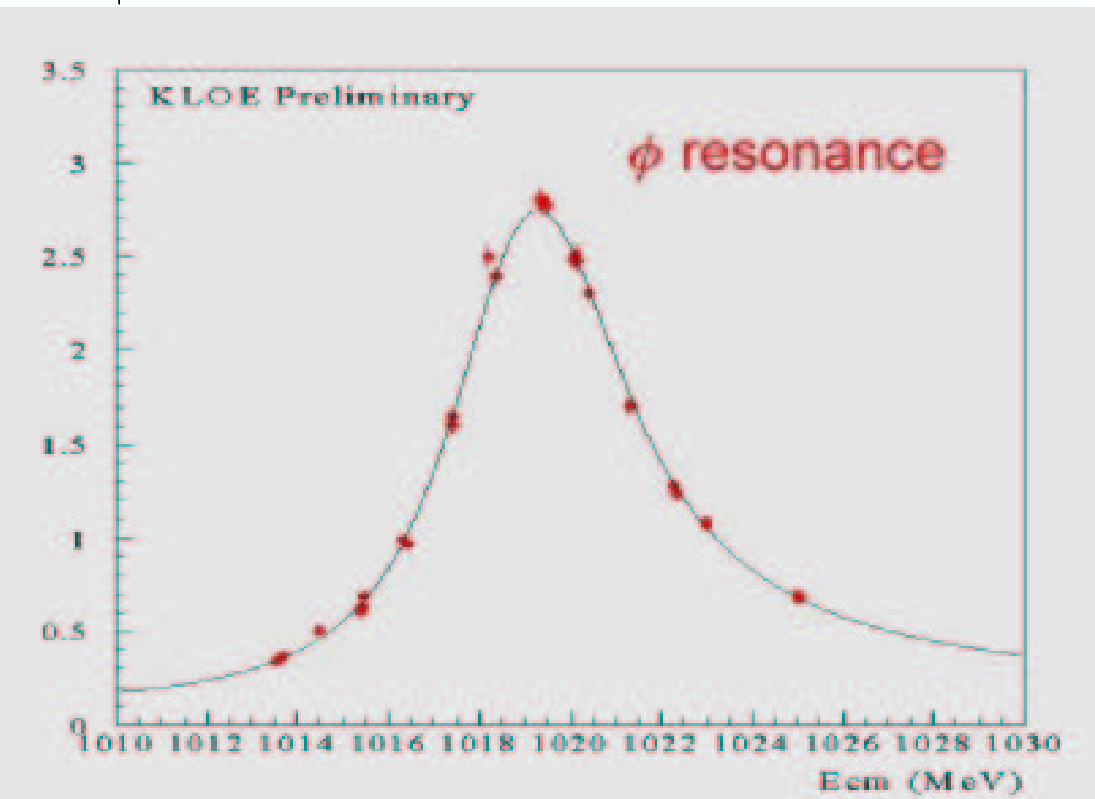
- **DAΦNE** status
- The **KLOE** experiment
- **KLOE** physics program:
  - Φ radiative decays
  - σ(had)
  - neutral Kaons
  - charged Kaons

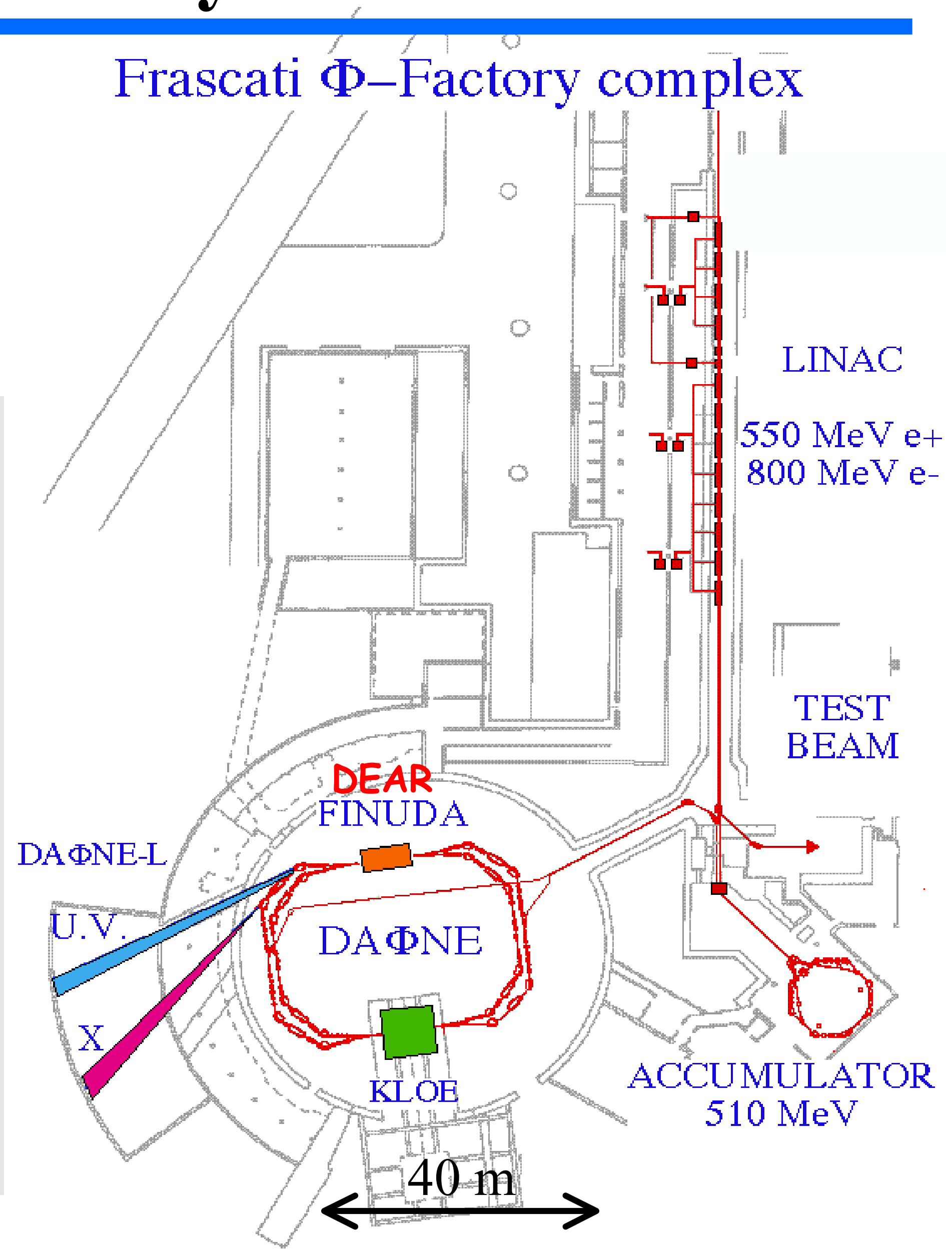
The KLOE Collaboration
presented by
Stefano Miscetti (INFN-LNF)

XXX Slac Summer Institute, 14 aug 2002

DAΦNE : the Frascati Φ factory

- $e^+e^- \to \phi \quad W = m_\phi = 1019.4$ MeV
- $\sigma_\phi \sim 3\ \mu b \to 1.5$ kHz at $5 \cdot 10^{32}\ cm^{-2}\ s^{-1}$





DAΦNE : the Frascati Φ factory

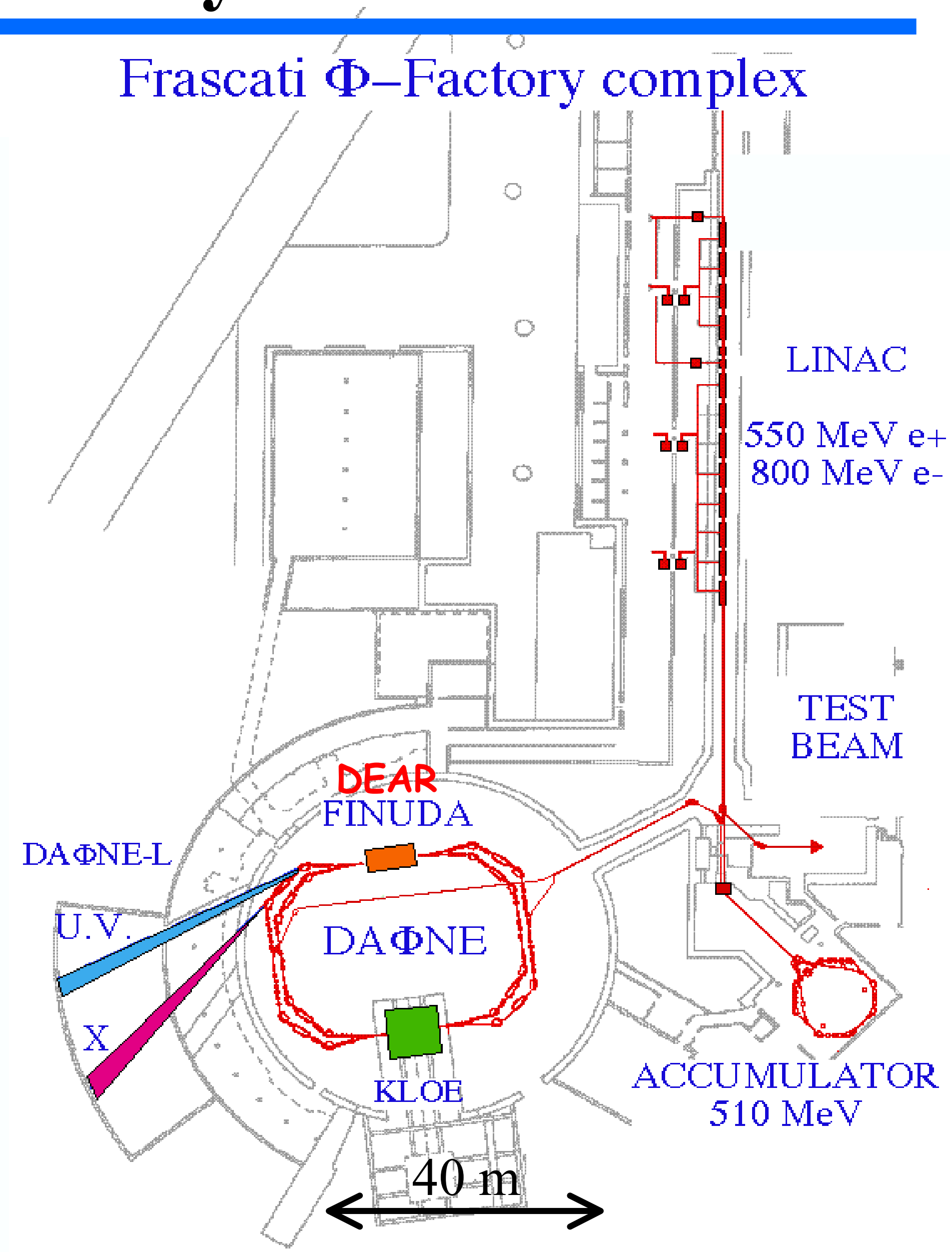
•Injection system: LINAC and accumulator

• Separate rings for electrons and positrons → 2 interaction regions

• KLOE experiment at IP1 → kaon physics, light mesons spettroscopy

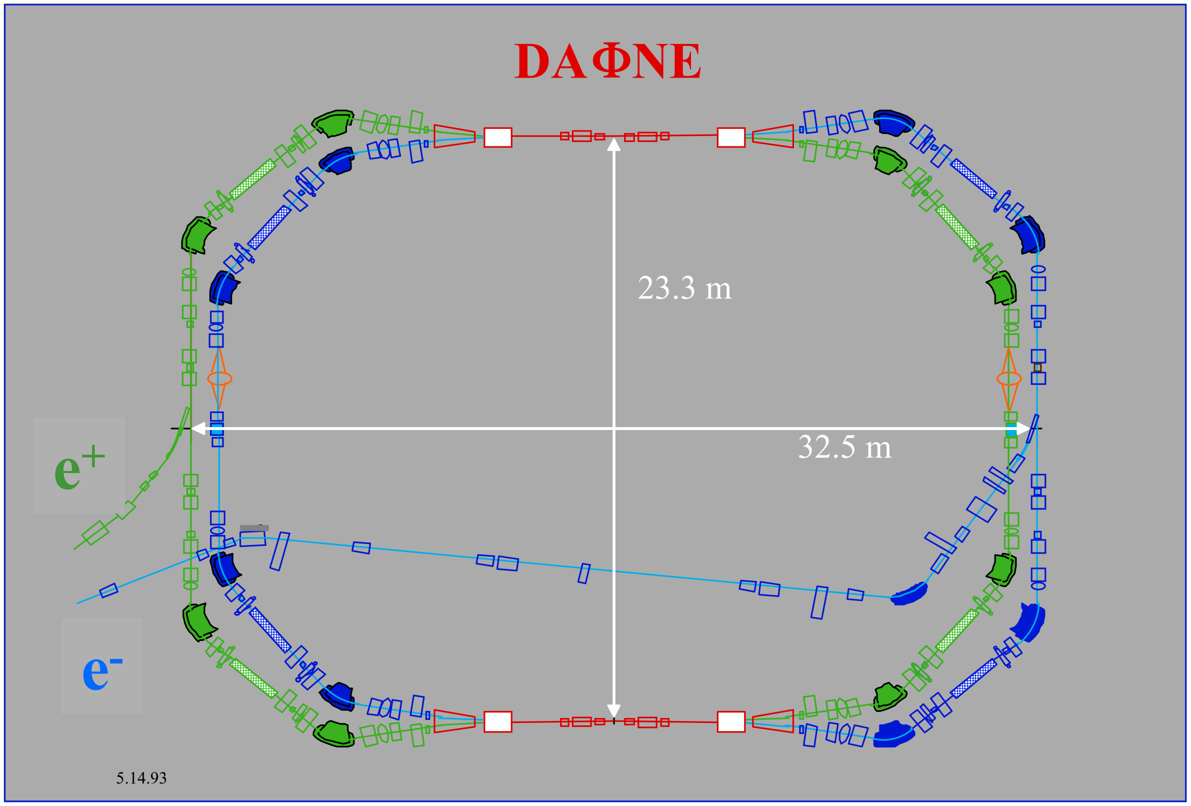
• DEAR experiment at IP2 → exotic atoms (FINUDA experiment will study Λ-hypernuclei)

• DAΦNE light: 3 beam lines installed



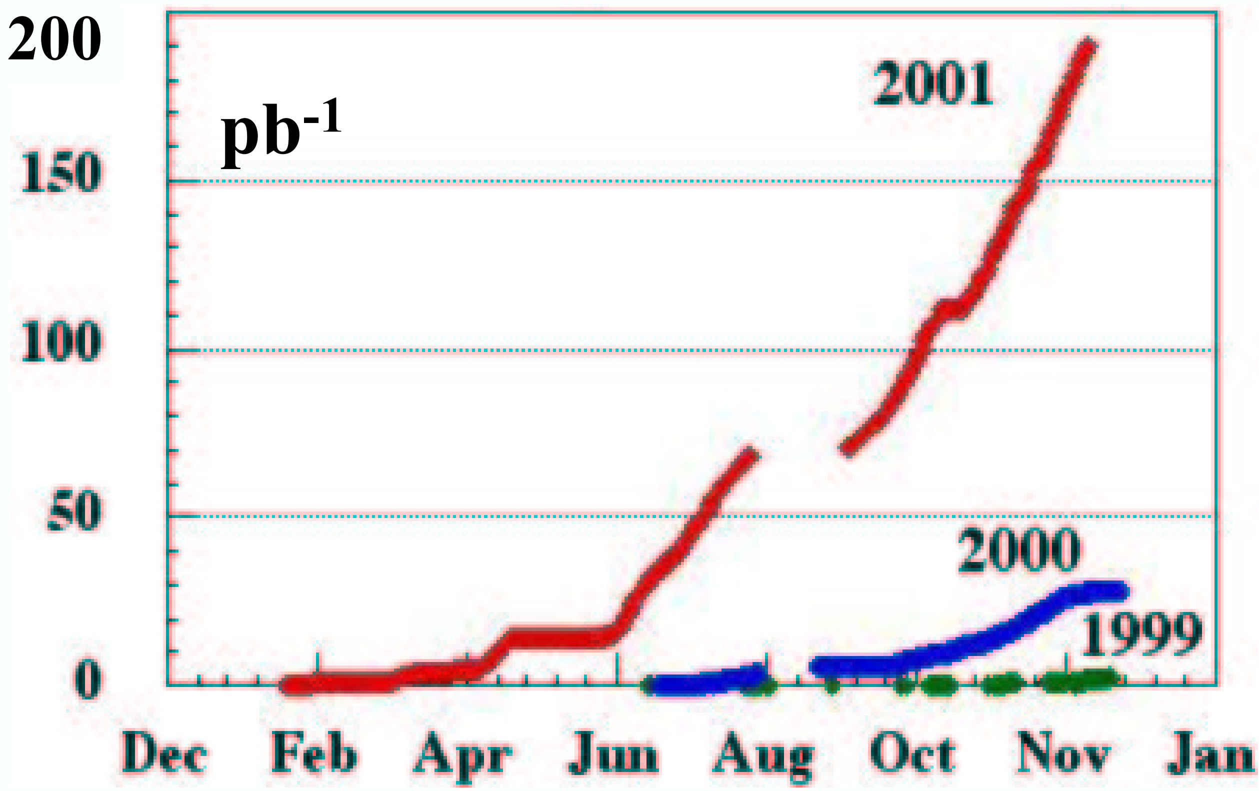
DAΦNE : main rings and performances

- High current to maximize luminosity (I_{max}= 5 A per beam) ⇒ 2 separate rings to minimize beam-beam interactions
- Beam energy 510 MeV/c
- Crossing angle 12.5 mrad → small ϕ momentum (13 MeV/c)



	DESIGN	TODAY
Number of bunches :	120	47
Bunch spacing :	2.7 ns	5.4 ns
Bunch current :	40 mA	20 mA
Single bunch luminosity :	$4 \cdot 10^{30}$ cm^{-2} s^{-1}	$1 \cdot 10^{30}$ cm^{-2} s^{-1}
Luminosity:	$5 \cdot 10^{32}$ cm^{-2} s^{-1}	$6 \cdot 10^{31}$ cm^{-2} s^{-1}

KLOE integrated luminosity



1999 run : **2.5 pb^{-1}**
machine and detector studies

2000 run : **25 pb^{-1}**
7.5 x 10^{7} ϕ
published results

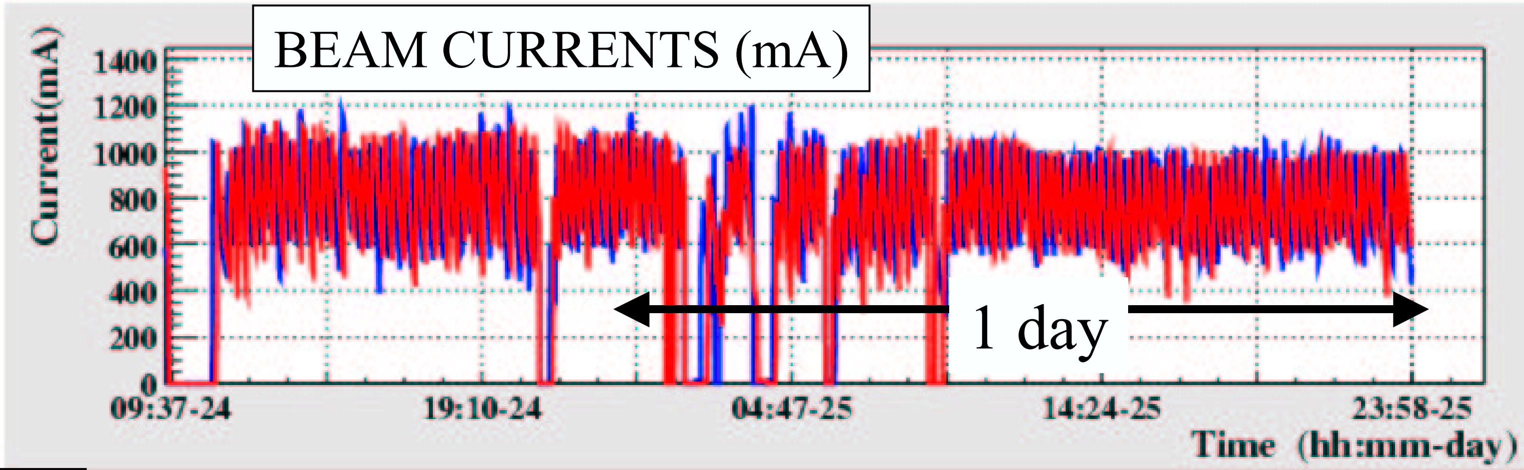
2001 run: **190 pb^{-1}**
5.7 x 10^{8} ϕ
analysis in progress

2002 : ~ **170 pb^{-1}** integrated from May up to now

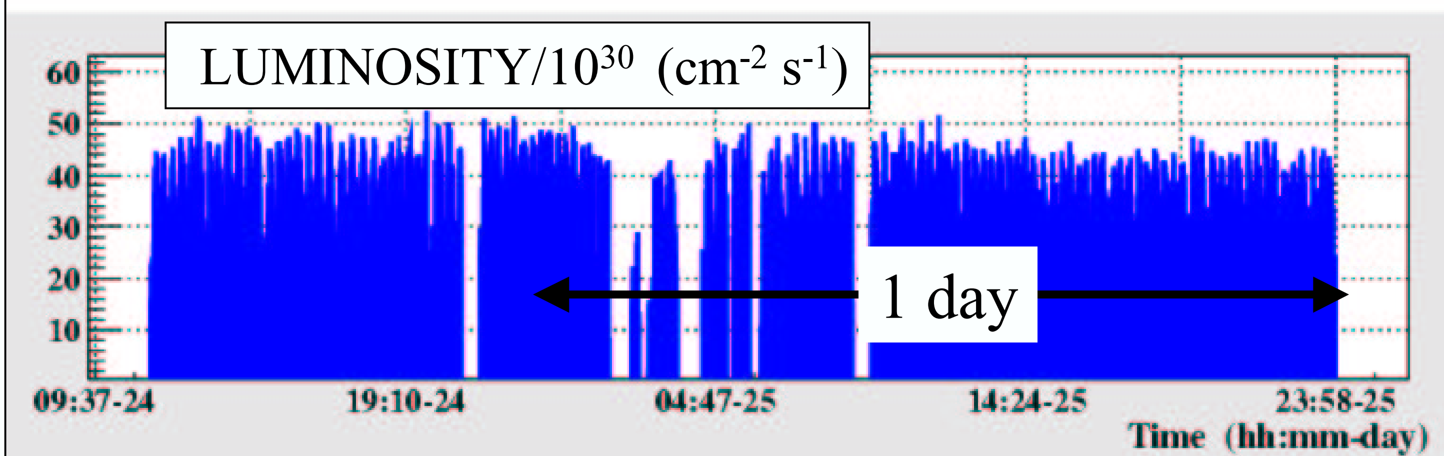
$\rightarrow$ **300 pb^{-1}** at run end (beginning of October)

DAΦNE performances: KLOE year 2001

$\langle I \rangle = 800$ mA



Refill during collisions every 15 minutes to maximize ∫ Ldt → continuous data taking during injection!! (5 ms veto gate)



	peak	average
L(cm^{-2} s^{-1})	$4.8\cdot 10^{31}$	$3.5\cdot 10^{31}$
$\int_{day} L\, dt$ (pb^{-1})	3	1.8

KLOE year 2002 commisioning run

- **Background Optimization**
  - Orbit Optimization (done, continuous)
  - Old and New Scrapers Optimization (done, continuous)
  - Sextupoles Optimization (done, continuous)
  - Octupoles Optimization (in progress..)
  - Increase Dynamic aperture with better β on Sexts. (in progress)
  - Increase lifetimes with larger β on Wigglers
- **Luminosity Optimization**
  - Adiabatic Tuning (in progress anytime)
  - Different Working Point for e- (done 1st pass)
  - Lower β^*_y (done 1st pass)
  - Low β^*_x (in progress)
  - Decrease horizontal emittance

DAFNE performance @ KLOE IP

	2001	2002

BACKGROUND estimate

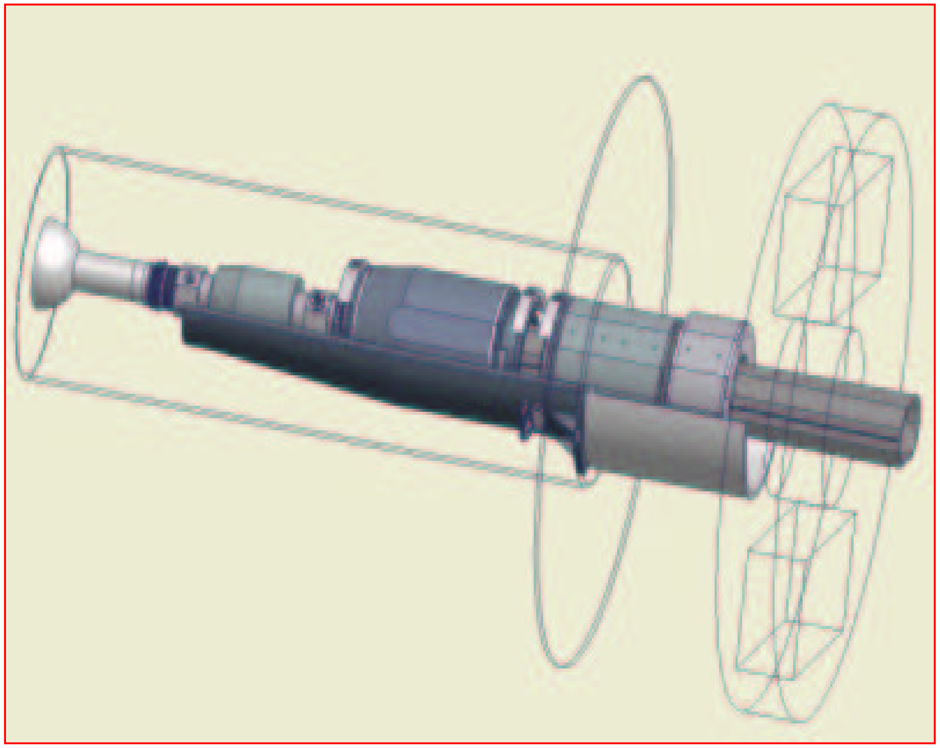
Ecap hot rate (West-East)	90-150 KHz -> 40-50 KHz
DCH noise (Khz)	15-20 KHz -> 9 KHz

Machine performances

• Number of bunches per beam	45+45 -> 47+47
• Total current per beam (A)	≈ 0.8-1.0
• Peak luminosity ($cm^{-2}s^{-1}$)	4.5 -> 6.2×10^{31}
• Average luminosity ($cm^{-2}s^{-1}$)	≈ 3.0 -> 4.5×10^{31}
• Integrated luminosity per day (pb^{-1})	2.0 -> 3.0
• Luminosity lifetime (h)	≈ 0.3 -> 0.4
• Number of fillings per hour	≈ 4
• Data acquisition during injection	on

DAFNE 2002 plans and prospects

- Deliver 300 pb^{-1} to KLOE
- Further improve luminosity and signal-to-background ratio in DEAR (≈ 50 pb^{-1})
- During a long shutdown (from Nov 2002 to Jan 2003) install new interaction regions for KLOE and for FI.NU.DA. with modified optics and supports in order to:
  - decrease the IP beta-functions,
  - optimise background rejection
  - provide variable quads rotation to operate at different B fields (from 0 to maximum) in the solenoids.



The KLOE experiment

$e^+ e^-$ collider at the ϕ mass

- Very clean environment
- Pure monochromatic $K\bar{K}$ beams:

$\mathbf{P_k = -P_{\bar{k}}}$ ($p_K \approx 110$ MeV/c) → **Efficient tagging**

$K\bar{K}$ pair has ϕ quantum numbers

($J^{PC} = 1^{--}$)

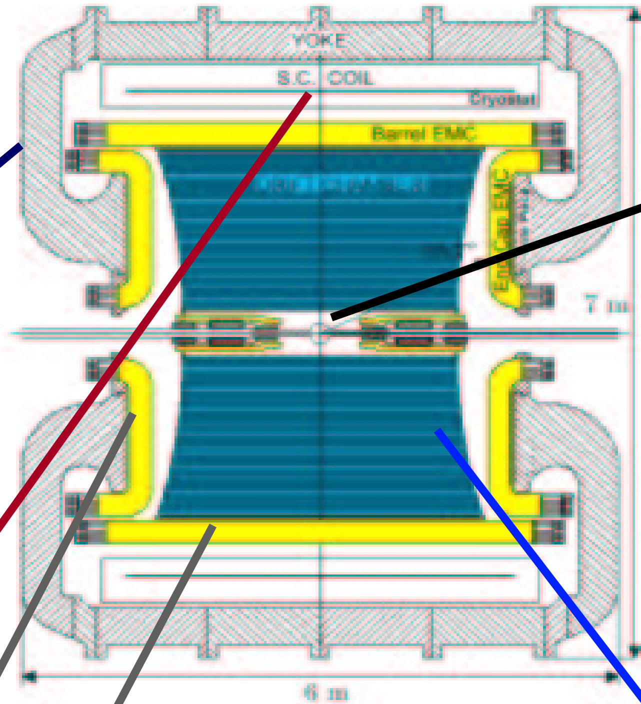
ϕ Decays	
K^+K^-	49.1%
K_LK_S	34.3%
$\rho\pi$	15.4%
$\eta\gamma$	1.3%

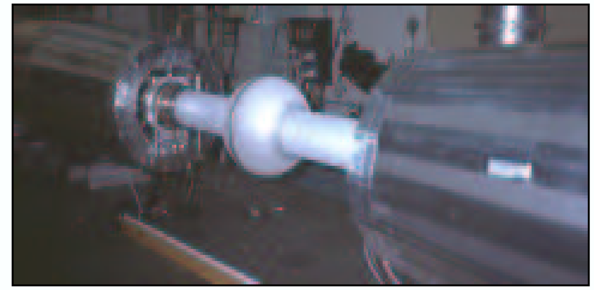
$\lambda(K_S) = 6$ mm ($\tau = 90$ ps)
$\lambda(K_L) = 3.5$ m ($\tau = 51.7$ ns)

The design of the experiment is driven by the measurement of direct CP violation through the double ratio

$R = \Gamma(K_L \to \pi^+\pi^-)\,\Gamma(K_S \to \pi^0\pi^0) / \Gamma(K_S \to \pi^+\pi^-)\,\Gamma(K_L \to \pi^0\pi^0)$

The KLOE detector



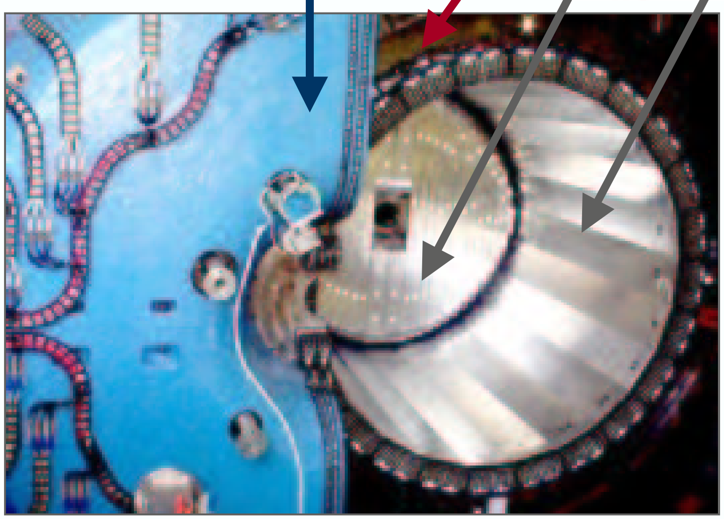


Interaction region:
Instrument quadrupoles,
Al-Be spherical beam pipe

SC Coil
5.188 kG

Iron Yoke

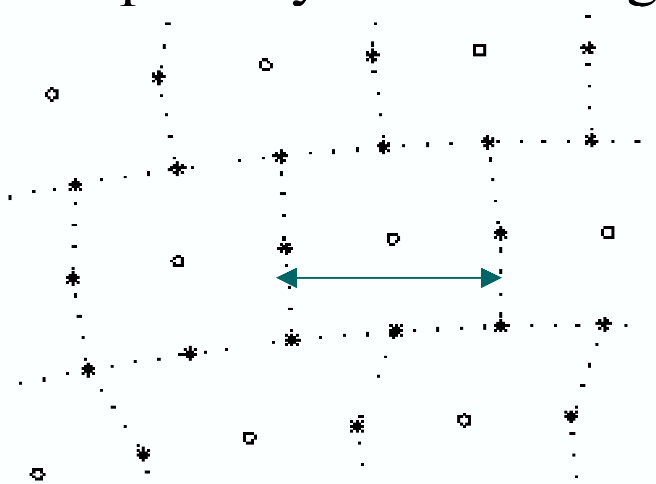
Big volume Drift Chamber
(13K cells, He gas mixt.)



Pb-SciFi Calorimeter
(barrel + endcap,
15 X_0 depth, 98%
solid angle coverage)

DC requirements and performances

- Good momentum resolution for low momentum tracks
- High and uniform rec. efficiency
- Trasparency to low energy photons



3 cm (2 cm for the 12 innermost layers)

4 m diameter × 3.3 m length

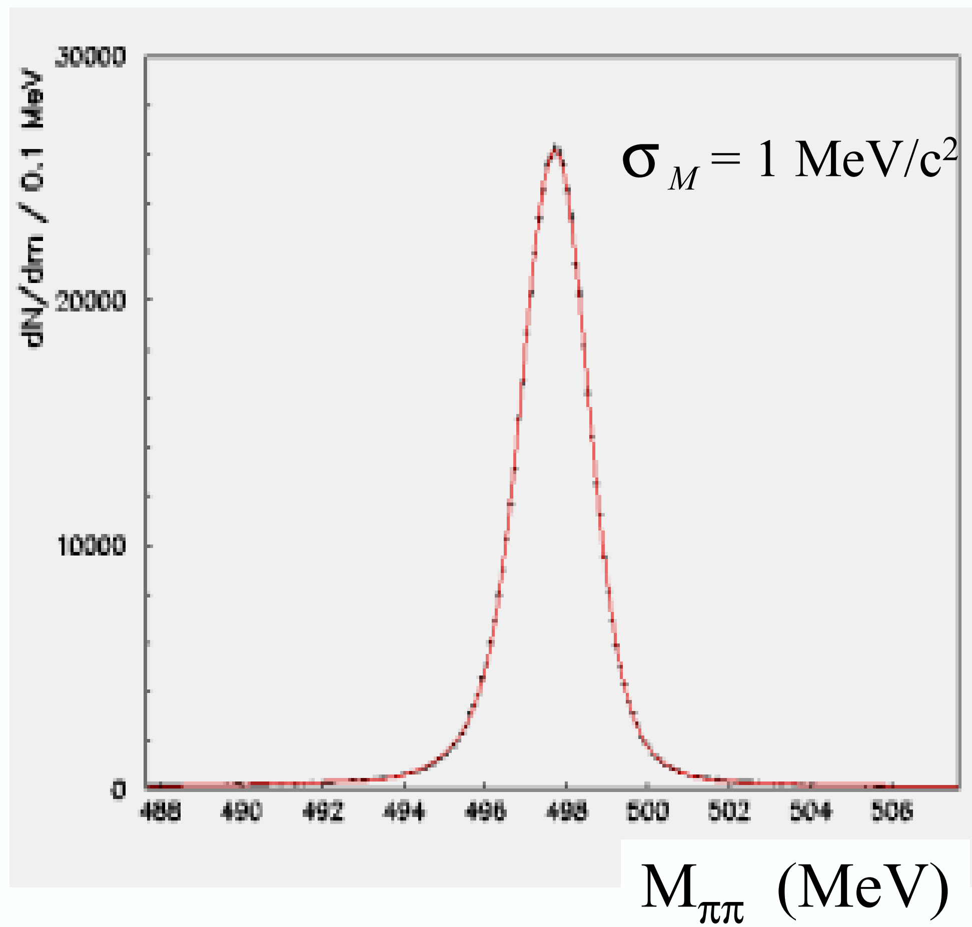
90% He-10% iC_4H_{10}

12582/52140 sense/total wires

All-stereo geometry

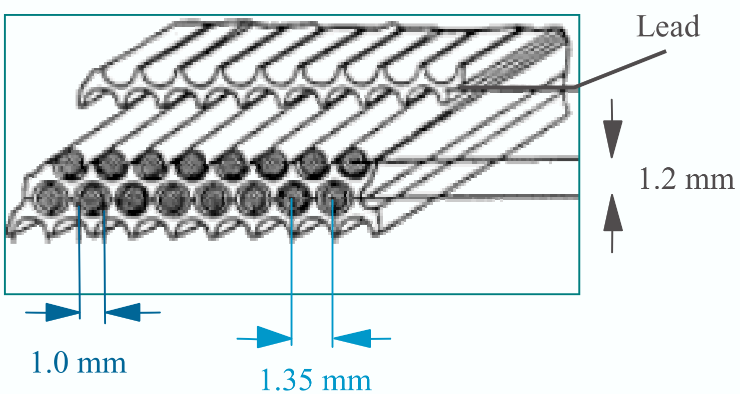
$\sigma_{r\phi}$ = 150 μm; σ_z = 2 mm

σ_p/p = 0.4 % (for 90° tracks)



EMC requirements and performances

- Determine the $K_{L,S}$ neutral vertex with few mm precision
- Discriminate $K_L \rightarrow \pi^0 \pi^0, \pi^0 \pi^0 \pi^0$
- Pid via time of flight

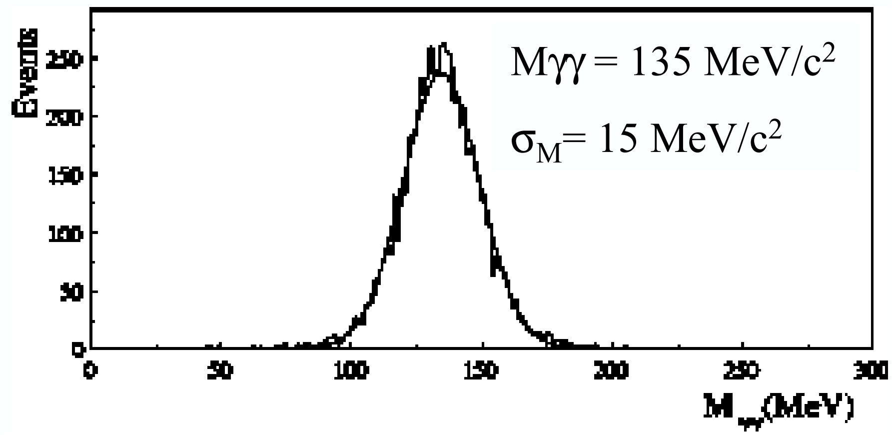


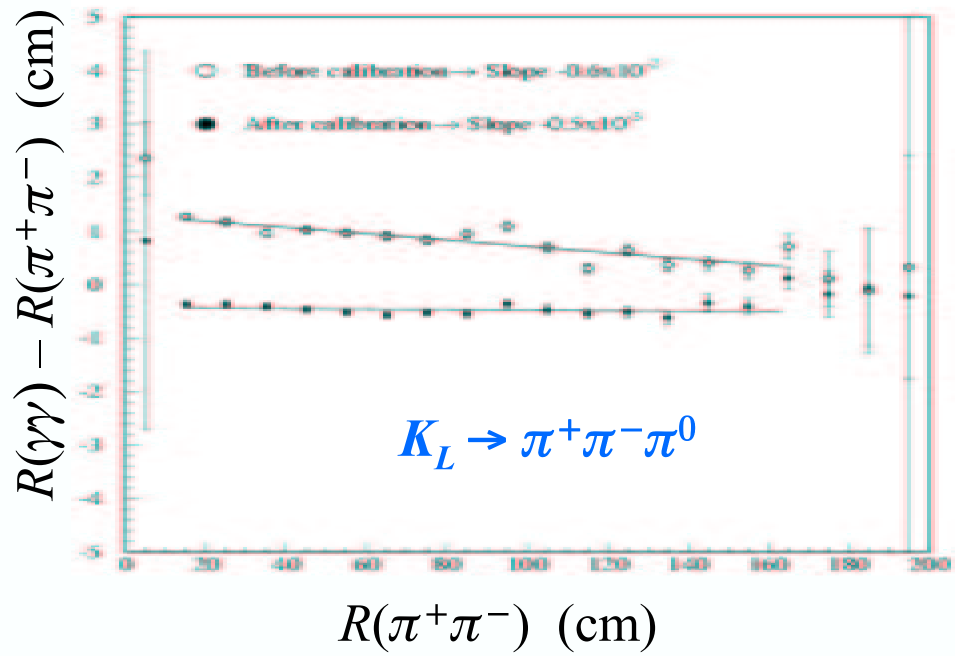
Fiber length up to 4.3 m (13000 km total)

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

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

High efficiency down to 20 MeV





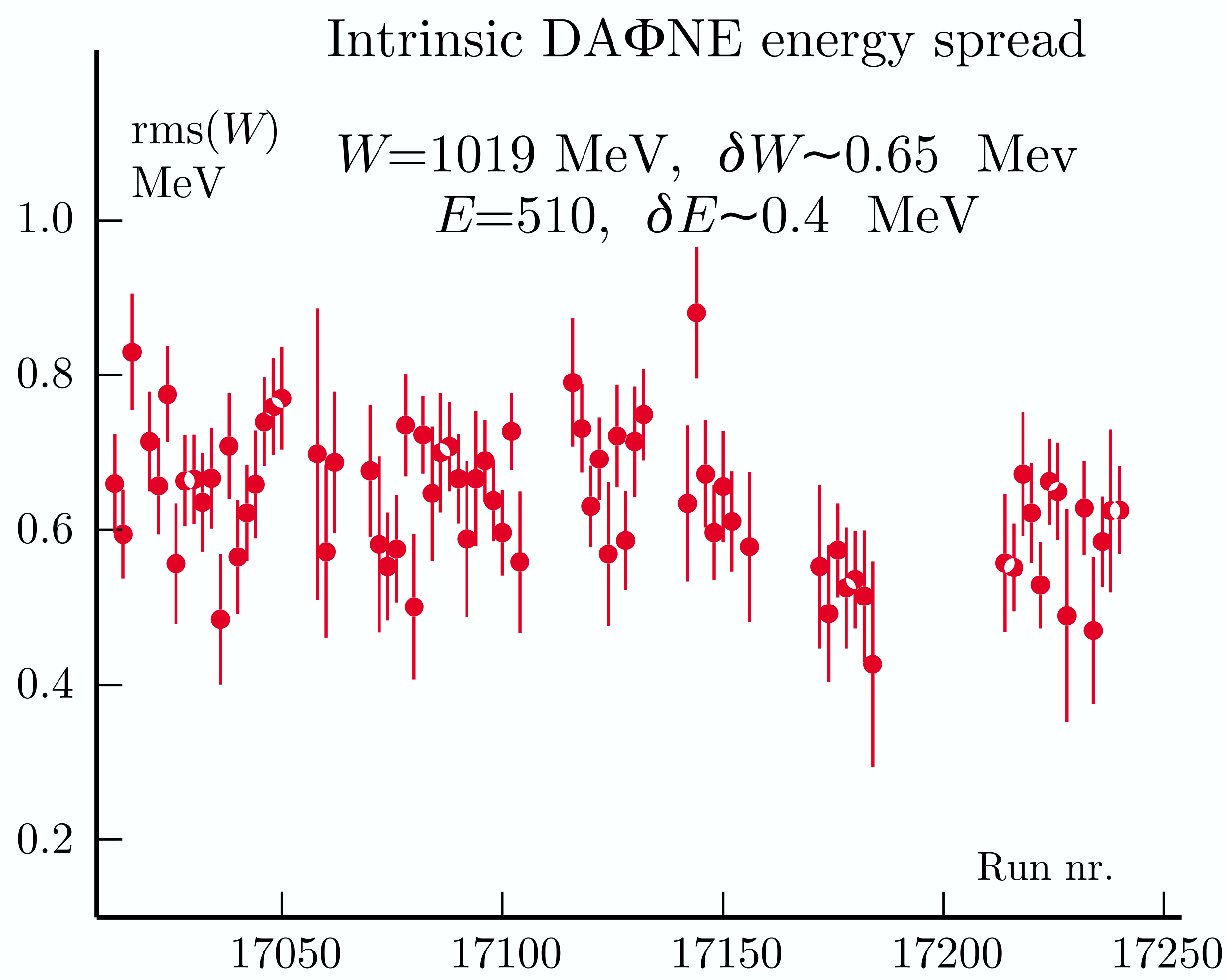
EMC + DC performances

We have two completely independent measurements of the c.m.s energy W :

- **W_1 from $P(K_s)$ (DC)**
- **W_2 from $B^*(K_l)$ (EMC)**

Both methods have resolution of around 1 MeV on W.

- Using **W1-W2 we control resolution** independently from beam energy spread
- Using **W1+W2 and unfolding resolution** we determine the intrinsic beam energy spread



KLOE physics program

Discrete symmetries

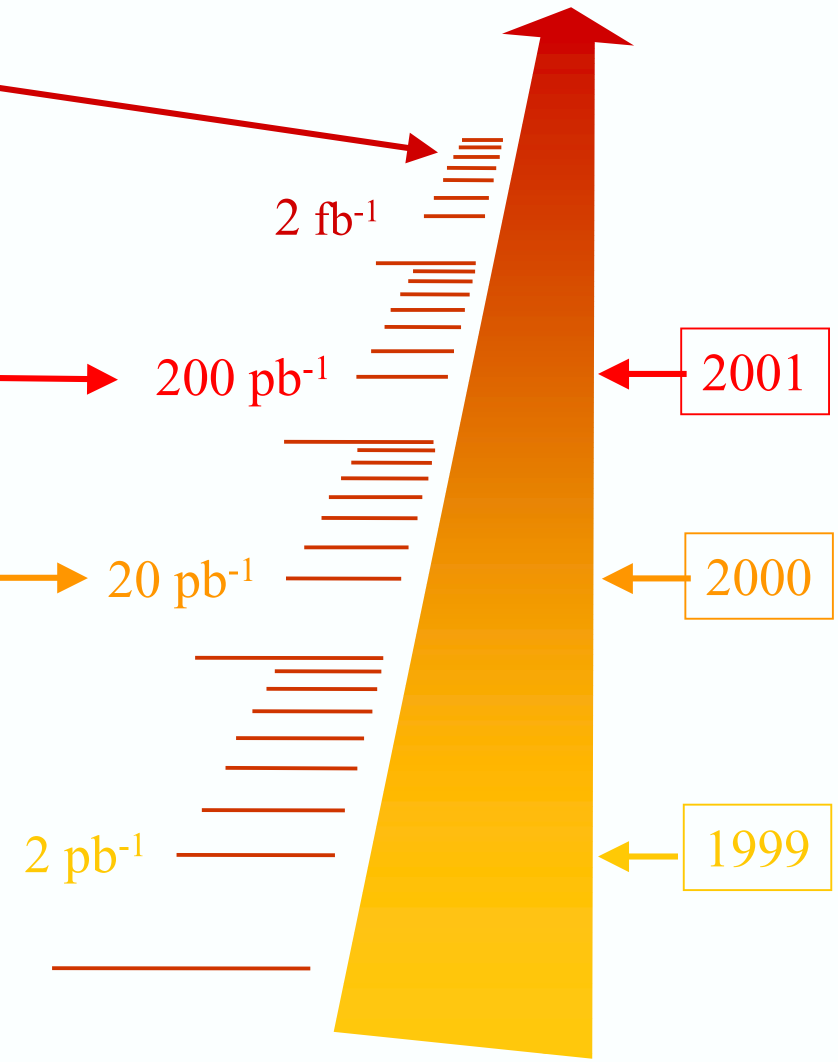
- ε'/ε to via double ratio (CP direct)
- Semileptonic asymmetry (CPT)
- $K_L K_S$ Interferometry

- $K_S \to \gamma\gamma$, $K_S \to 3\pi$, $K_S \to \pi\pi\gamma$
- $K_L \to 2\pi$, $K_L \to \gamma\gamma$
- V_{us} from $K^{\pm}$ and K_L decays
- $\sigma(e^+e^- \to \pi^+\pi^-)$ to < 1 % (stat)

on tape

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

first published results



ϕ radiative decays

Channel	BR (PDG)	
$\eta\gamma$	1.26×10^{-2}	
$\pi^0\gamma$	1.3×10^{-3}	$\phi \longrightarrow P\,(0^{-+})\,\gamma$
$\eta'\gamma$	$\sim 10^{-4}$	
$\pi\pi\gamma$	$\sim 10^{-4}$	$\phi \longrightarrow S\,(0^{++})\,\gamma \quad S \longrightarrow \pi\pi\,/\,\eta\pi$
$\eta\pi^0\gamma$	$\sim 10^{-4}$	

Analysis of 2000 data on:

$\phi \longrightarrow \pi^0\pi^0\gamma$ Phys.Lett. **B 537** (2002), 21

$\phi \longrightarrow \eta\pi^0\gamma$ Phys.Lett. **B 536** (2002), 209

$\phi \longrightarrow \eta'\gamma\,/\,\eta\gamma$ Phys.Lett. **B 541** (2002), 45

$\phi \rightarrow$ pseudoscalar + γ : $\eta\gamma$, $\eta'\gamma$

According to quark model (assuming no gluonic content):

$$\pi^0 = (uu - dd)/\sqrt{2}$$

$$\eta = \cos\alpha_P\,(uu+dd)/\sqrt{2} + \sin\alpha_P\,ss$$

$$\eta' = -\sin\alpha_P\,(uu+dd)/\sqrt{2} + \cos\alpha_P\,ss$$

Assuming: ϕ = ss state ($\alpha_V = 0$):

$$\mathbf{R} = \frac{\Gamma(\phi \rightarrow \eta'\gamma)}{\Gamma(\phi \rightarrow \eta\,\gamma)} = \mathbf{cotg^2\alpha_P \left(\frac{K_{\eta'}}{K_\eta}\right)^3 F(\alpha_P, \alpha_V)}$$

(F slowly varying function, model dependent)

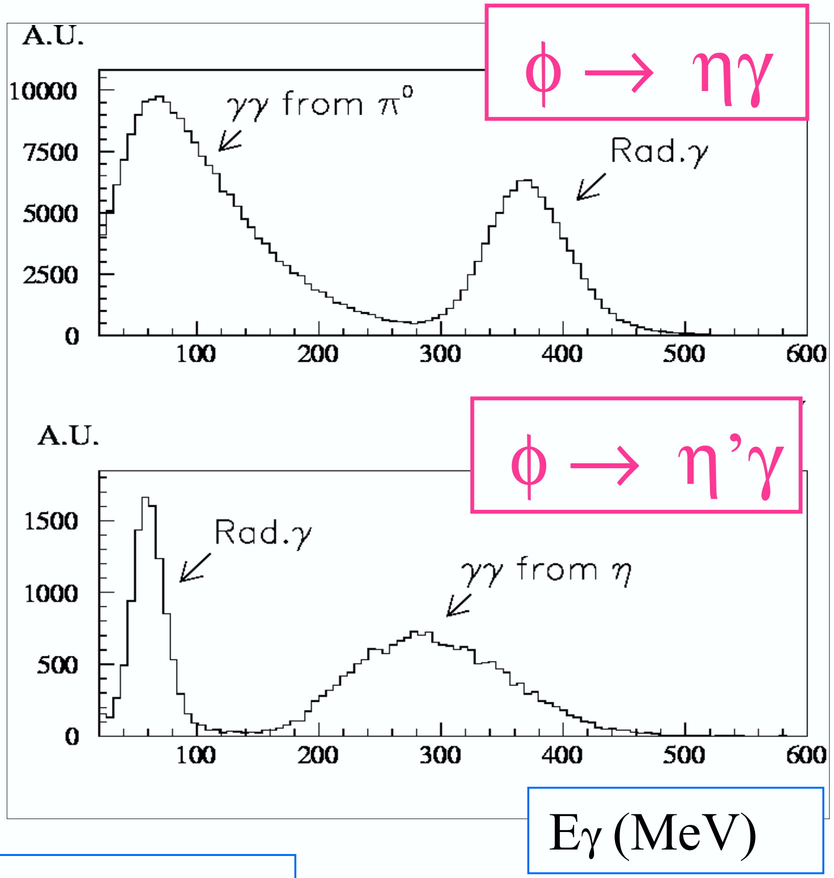
We measure R to obtain:

- ✓ **A precise measurement of BR($\phi \rightarrow \eta'\gamma$)**
- ✓ **The η–η' mixing angle**

$\phi \to$ pseudoscalar + γ : $\eta\gamma$, $\eta'\gamma$

Used decay chains:

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



Same topology: two tracks + three photons
Different kinematics in the final state

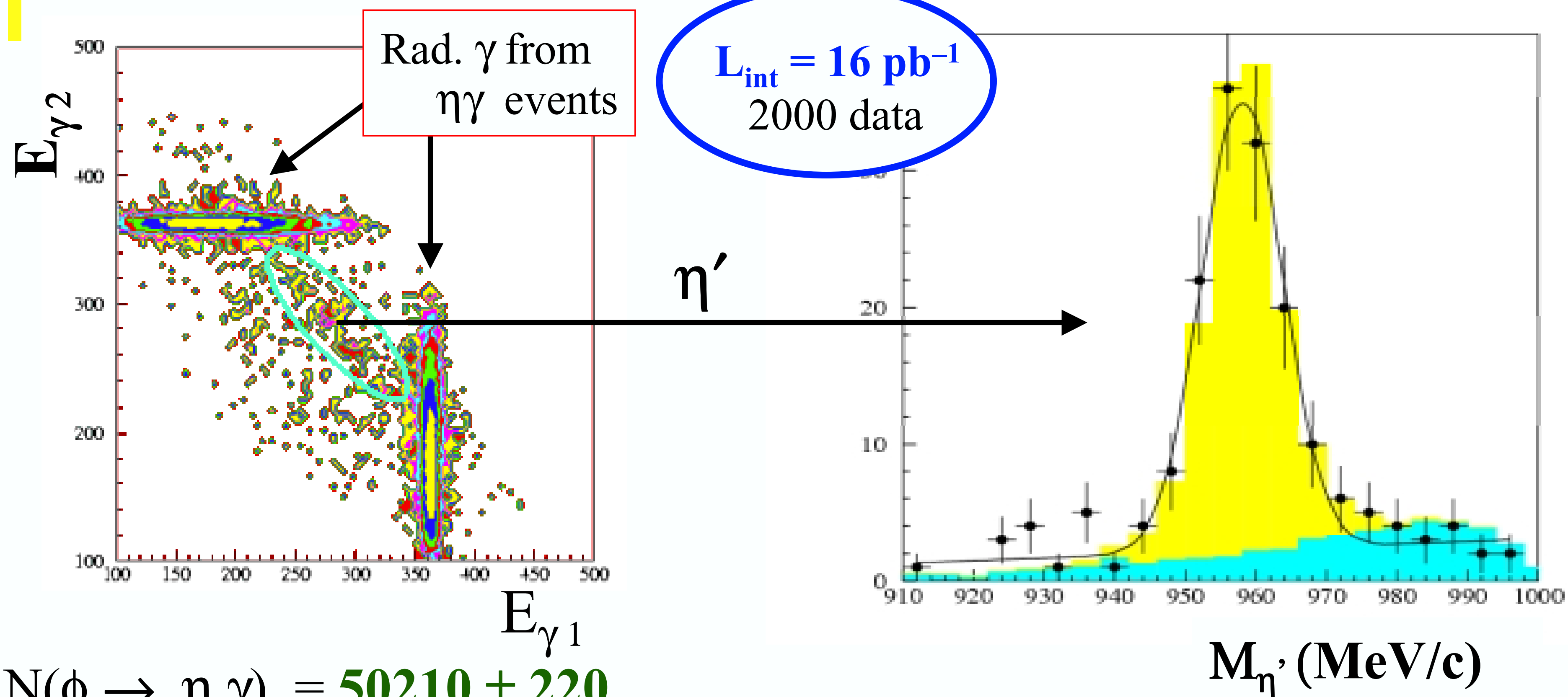
Background from
$\phi \to \pi^+\pi^-\pi^0$ and $\phi \to K_S K_L$

- a 2 tracks vertex close to IP
- 3 neutral clusters on time $|T-R/c| < 5\,\sigma_t$
- Kinematic fit imposing global 4-momentum at IP

➡ loose χ^2 cut + topological cuts on E_1 E_2 plane

$\varepsilon(\eta\gamma) = 36.5\%$
$\varepsilon(\eta'\gamma) = 22.8\%$

$\Gamma(\phi \to \eta'\gamma) / \Gamma(\phi \to \eta\gamma)$: results



$N(\phi \to \eta\gamma)$ = **50210 ± 220**

$N(\phi \to \eta'\gamma)$ = **$120 \pm 12_{stat} \pm 5_{bckg}$**

$R = (4.70 \pm 0.47_{stat} \pm 0.31_{syst}) \times 10^{-3}$

- **Bkg (4.2%) vtx(0.9%) clus(0.8+0.5%) χ^2 (2.3%) presel (2.2%) PDG (3.8%)**
- **$\alpha_P = (41.8 \pm 1.7)^o$**
- Using PDG for $BR(\phi \to \eta\gamma)$ **$BR(\phi \to \eta'\gamma) = (6.10 \pm 0.61_{stat} \pm 0.43_{syst}) \times 10^{-5}$**

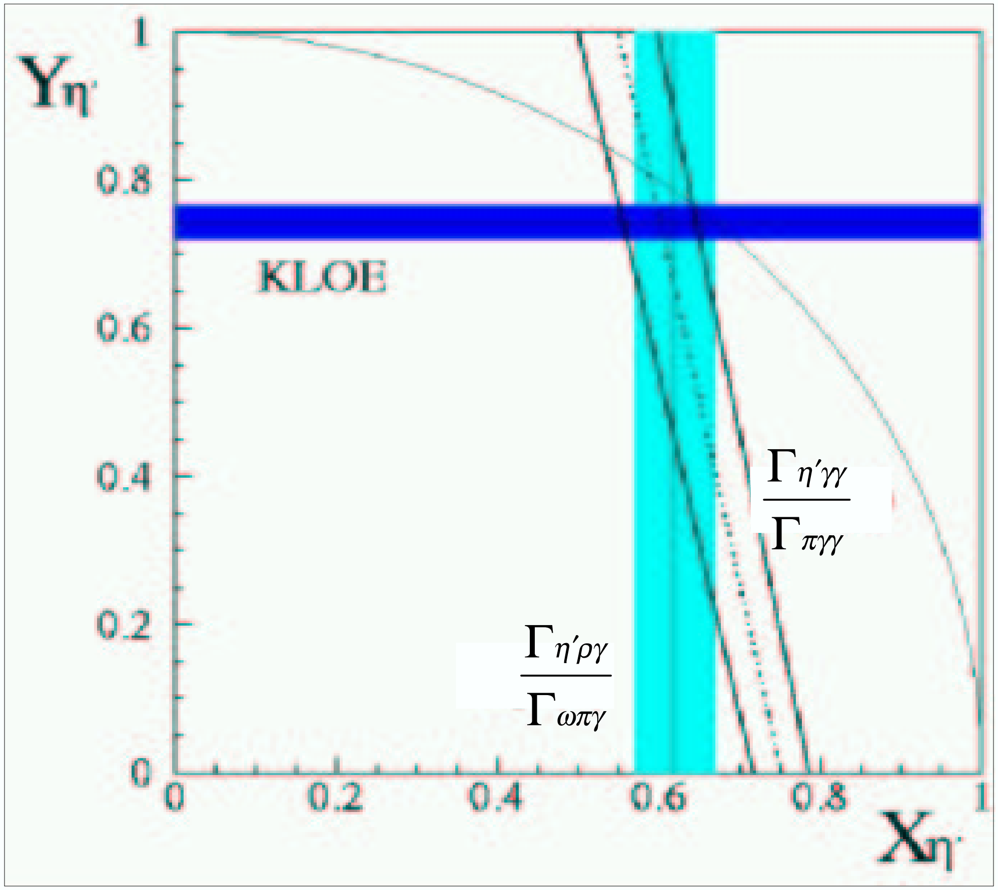
Gluon content of η'

Combined analysis:

$\eta' = X_{\eta'}(u\bar{u}+d\bar{d}) + Y_{\eta'} s\bar{s} + Z_{\eta'} gg$

Assuming $Z_{\eta'} = 0$:

1. Constraints on $X_{\eta'}$, $Y_{\eta'}$ from other channels
2. $Y_{\eta'} = \cos\varphi_p$ from KLOE
3. Check consistency in the $X_{\eta'}$-$Y_{\eta'}$ plane with $X_{\eta'}^2 + Y_{\eta'}^2 = 1$



Minimizing the related χ^2 function:

$Z_{\eta'}^2 = 0.06^{+0.09}_{-0.06}$

Gluon content of η' lower than 15%

$\phi \to \eta'\gamma \to \pi^+\pi^-7\gamma$

KLOE Preliminary

Two contributions:

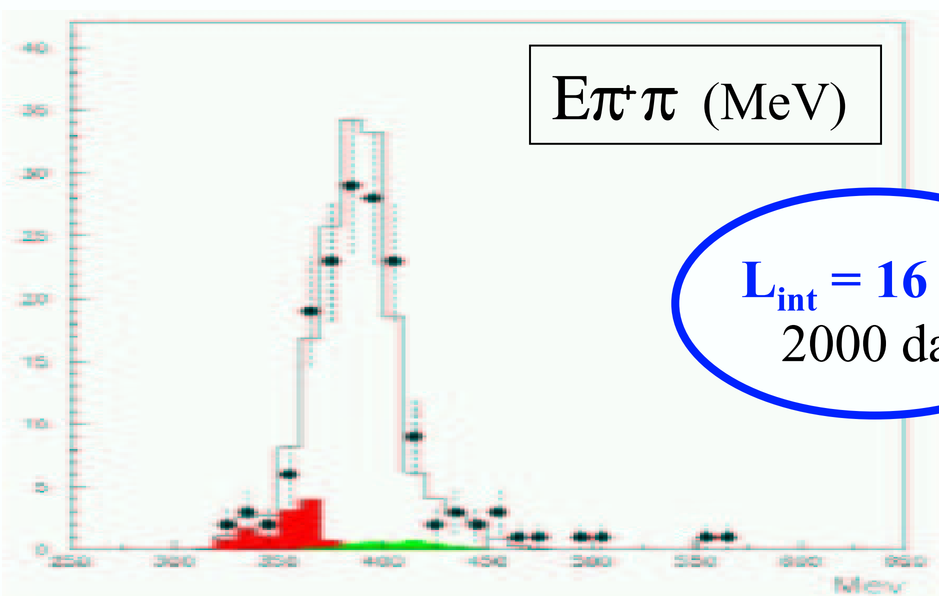
- $\eta' \to \eta\pi^+\pi^-$
  - $\hookrightarrow \pi^0\pi^0\pi^0$
- $\eta' \to \eta\,\pi^0\pi^0$
  - $\hookrightarrow \pi^+\pi^-\pi^0$
- ❑ Bckg from $\phi \to K_S K_L$

First observation of these decays

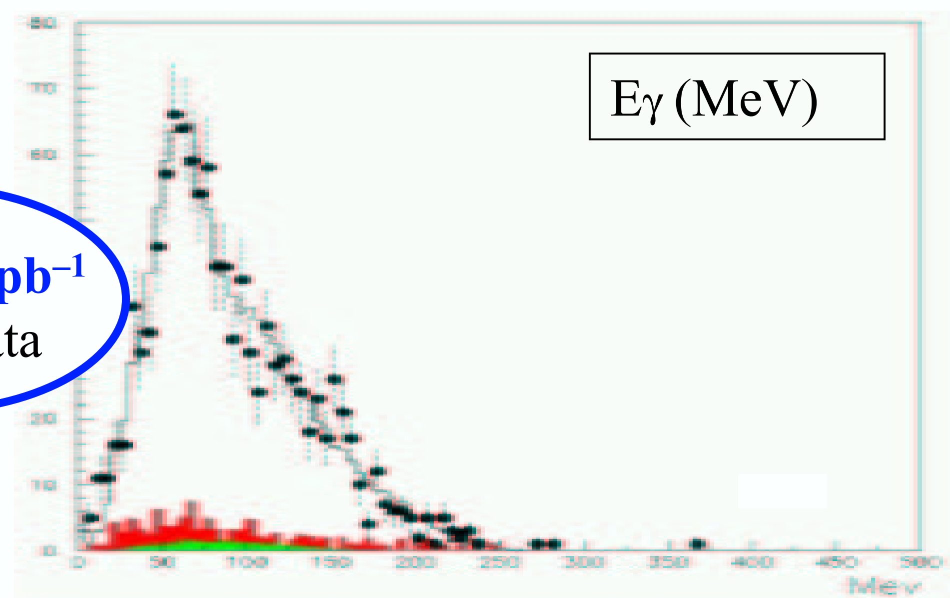
$N_{\pi+\pi-7\gamma} = 155 \pm 12$

$$BR(\phi \to \eta'\gamma) = (7.05 \pm 0.61^{+0.94}_{-0.97}) \times 10^{-5}$$

In agreement with the $\phi \to \eta'\gamma \to \pi^+\pi^- 3\gamma$ analysis



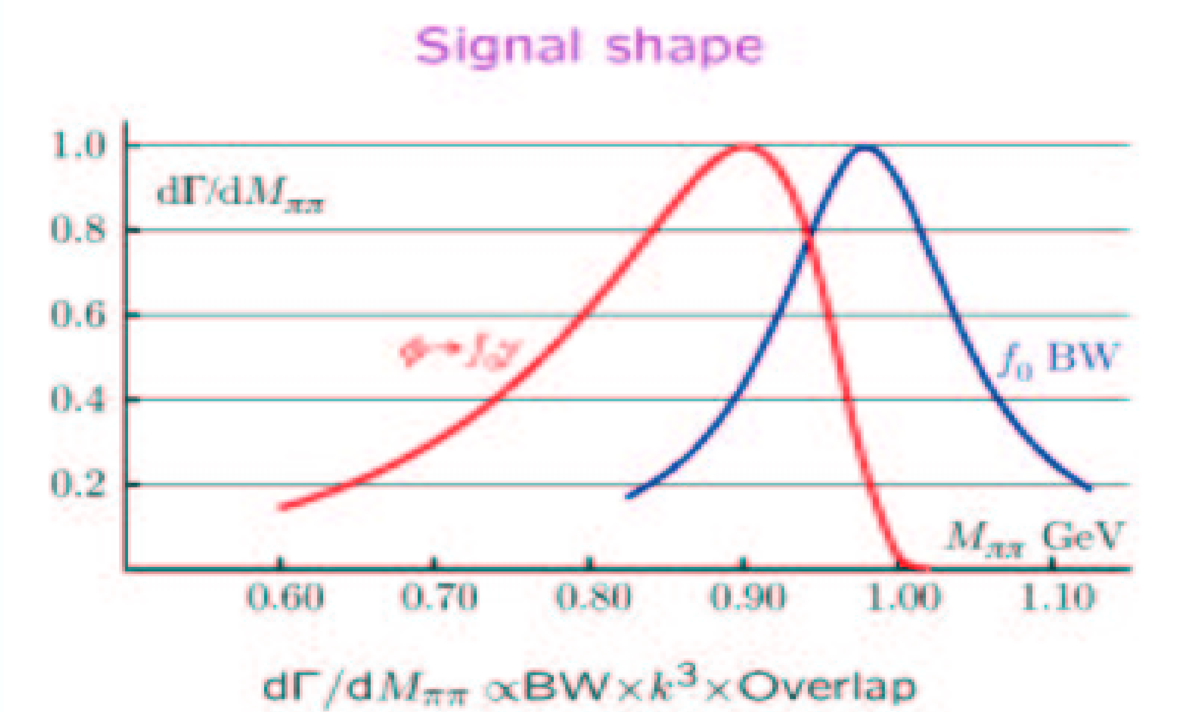
$L_{int} = 16\ pb^{-1}$
2000 data



$\phi \to$ **Scalar Meson** + γ [f_0(980) **I=0,** a_0(980) **I=1**]

- f_0, a_0 not easily interpreted as $q\bar{q}$ states; other interpretations suggested:
  - → $qq\bar{q}\bar{q}$ states [*Jaffe 1977*]
  - → $K\bar{K}$ molecule [*Weinstein, Isgur 1990*]

- $\phi \to f_0\gamma$, $a_0\gamma$ BR, mass spectra sensitive to f_0,a_0 nature [*Achasov, Ivanchenko 1989*]

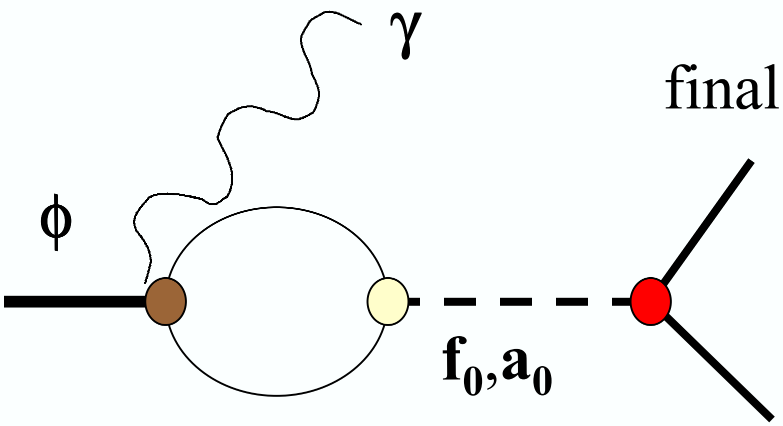


$$\frac{d\Gamma(\phi \to S\gamma \to ab\gamma)}{dm} = \frac{2m^2}{\pi} \frac{\Gamma(\phi \to S\gamma)\Gamma(S \to ab)}{|D_S|^2}$$

$\phi \to$ Scalar Meson + γ [$f_0(980)$ **I=0**, $a_0(980)$ **I=1**]

Kaon loop approach

- Approach:extract phenomenological coupling constants



Kaon loop

final state: $f_0 \to \pi^0\pi^0$, $a_0 \to \eta\pi^0$

- $g(\phi KK)$ $\Rightarrow$ from $\Gamma(\phi \to K^+K^-)$
- $g(f_0KK)$ $g(a_0KK)$ } $M(\pi^0\pi^0)$, $M(\eta\pi)$ spectra
- $g(f_0\pi\pi)$ $g(a_0\eta\pi)$

Final states: 5 photons ($f_0 \to \pi^0\pi^0$, $a_0 \to \eta\pi^0 \to \gamma\gamma\pi^0$)
2 tracks +5 photons ($a_0 \to \eta\pi^0 \to \pi^+\pi^-\pi^0\pi^0$)

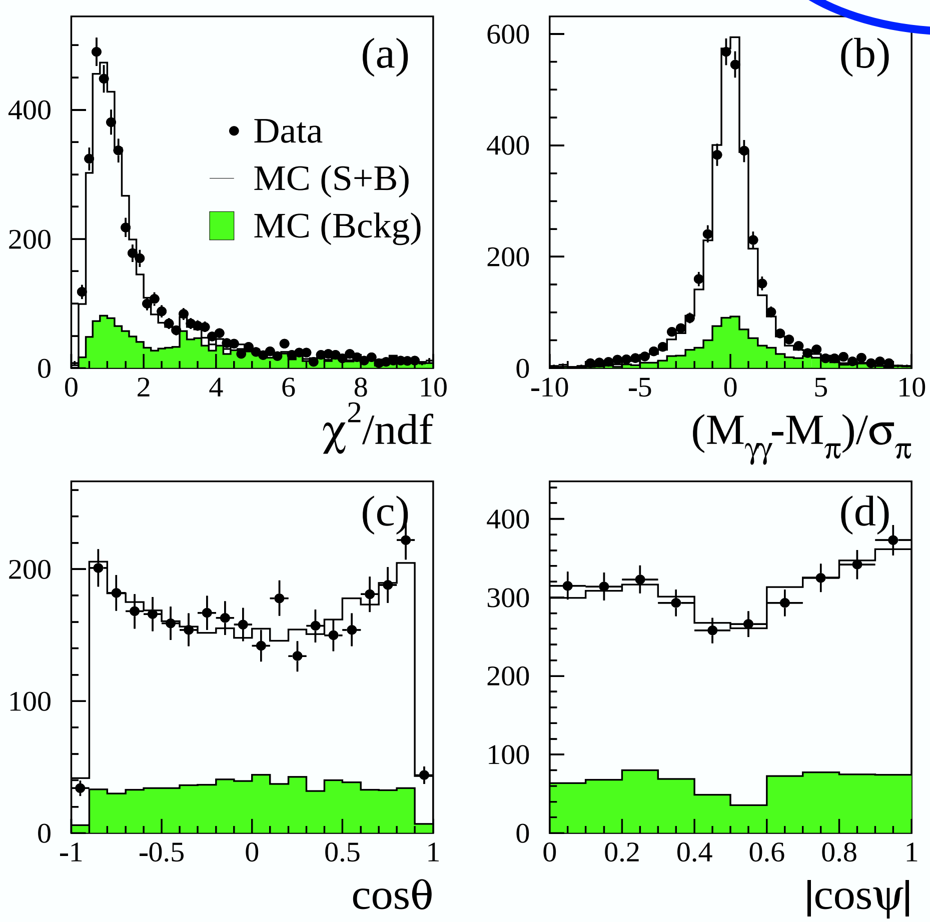
Sample selection:
- 5 prompt photons (+ 2 tracks from IP)
- Kinematic fit + topological cuts

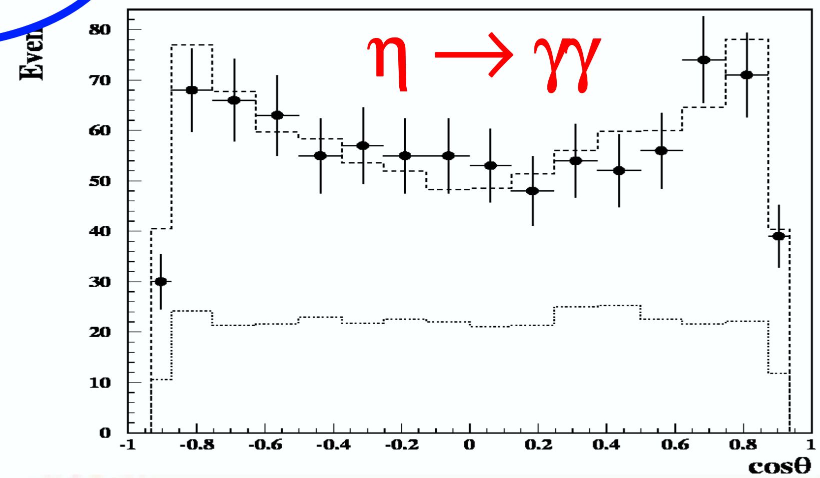
$\phi \to f_0(980)\gamma / a_0(980)\gamma$: data quality

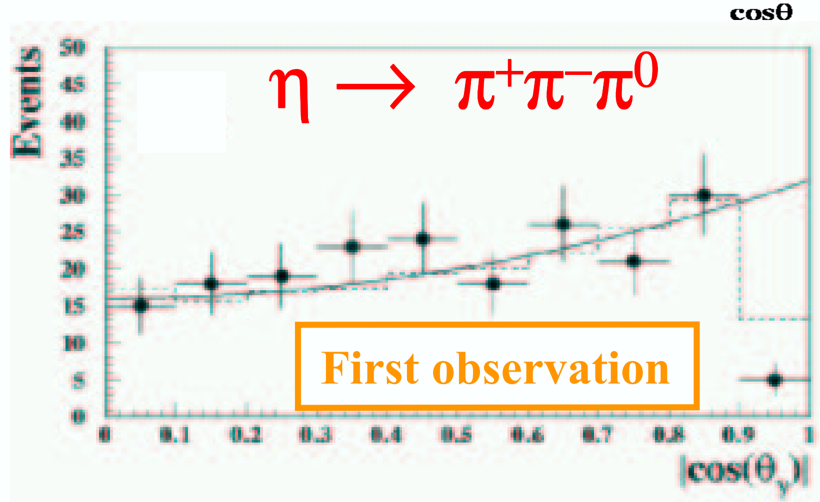
$\phi \to f_0\gamma \to \pi^0\pi^0\gamma$

$L_{int} = 16\ pb^{-1}$
2000 data

$\phi \to a_0\gamma \to \eta\pi^0\gamma$







$\phi \to f_0(980)\gamma \to \pi^0\pi^0\gamma$

$N_{\pi\pi\gamma}$ = **2438 ± 61**

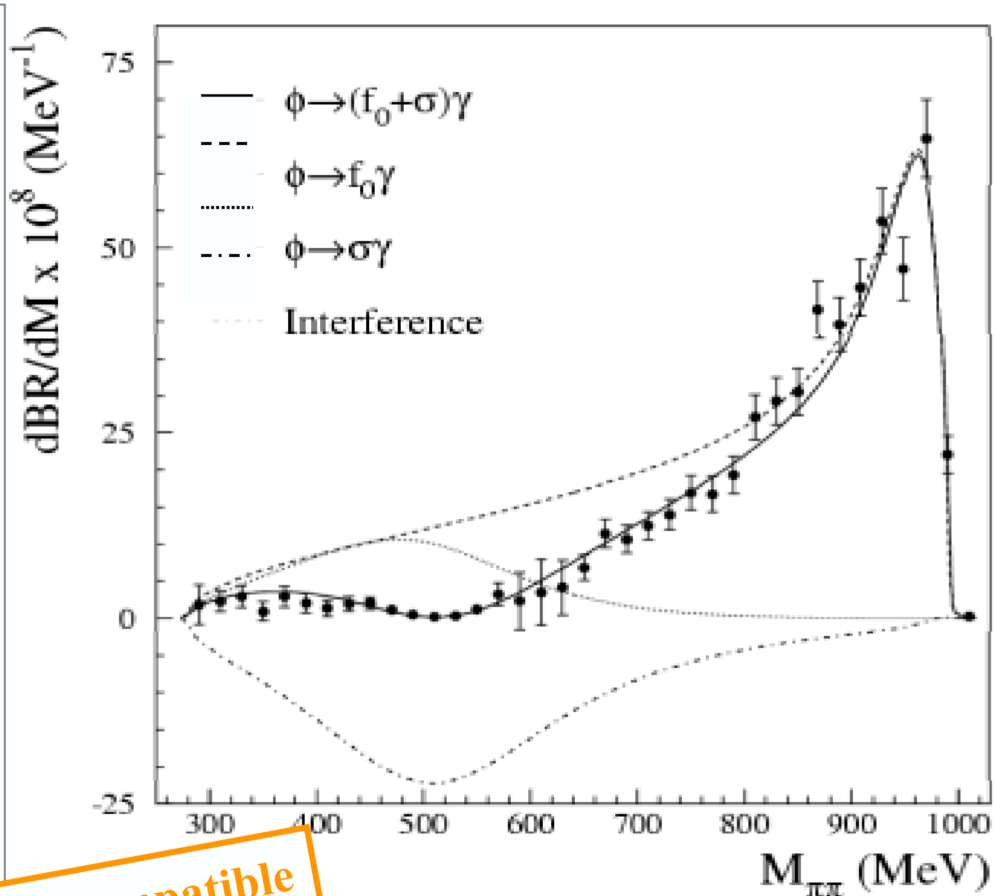
BR($\phi \to \pi^0\pi^0\gamma$)=
$(1.09 \pm 0.03_{stat} \pm 0.05_{syst})$ x 10^{-4}

[CMD-2 : (0.92 ± 0.08 ± 0.06) x 10^{-4}]
[SND : (1.14 ± 0.10 ± 0.12) x 10^{-4}]

Fit to the $M_{\pi\pi}$ spectrum with:

1) $\phi \to f_0\gamma \to \pi^0\pi^0\gamma$
2) $\phi \to \sigma\gamma \to \pi^0\pi^0\gamma$
3) $\phi \to \rho^0\pi^0 \to \pi^0\pi^0\gamma$

- **Strong 1) , 2) negative interference**
- **Negligible contribution from 3)**



Parameters compatible with qqqq model

Fit results

- $M(f_0)$ = 973 ± 1 MeV
- BR($\phi \to f_0\gamma \to \pi^0\pi^0\gamma$) = (1.49 ± 0.07)10^{-4}
- $g^2(f_0KK)/4\pi$ = 2.79 ± 0.12 GeV^2
- $g(f_0\pi\pi)/g(f_0KK)$ = 0.50 ± 0.01
- $g(\phi\sigma\gamma)$ = 0.060 ± 0.008

$\phi \to a_0(980)\gamma \to \eta\pi^0\gamma$

$N_{\eta\pi\gamma}$ = **607 ± 36** [$\eta \to \gamma\gamma$]

BR($\phi \to \eta\pi^0\gamma$)=
($8.5 \pm 0.5_{stat} \pm 0.6_{syst}$) x 10^{-5}

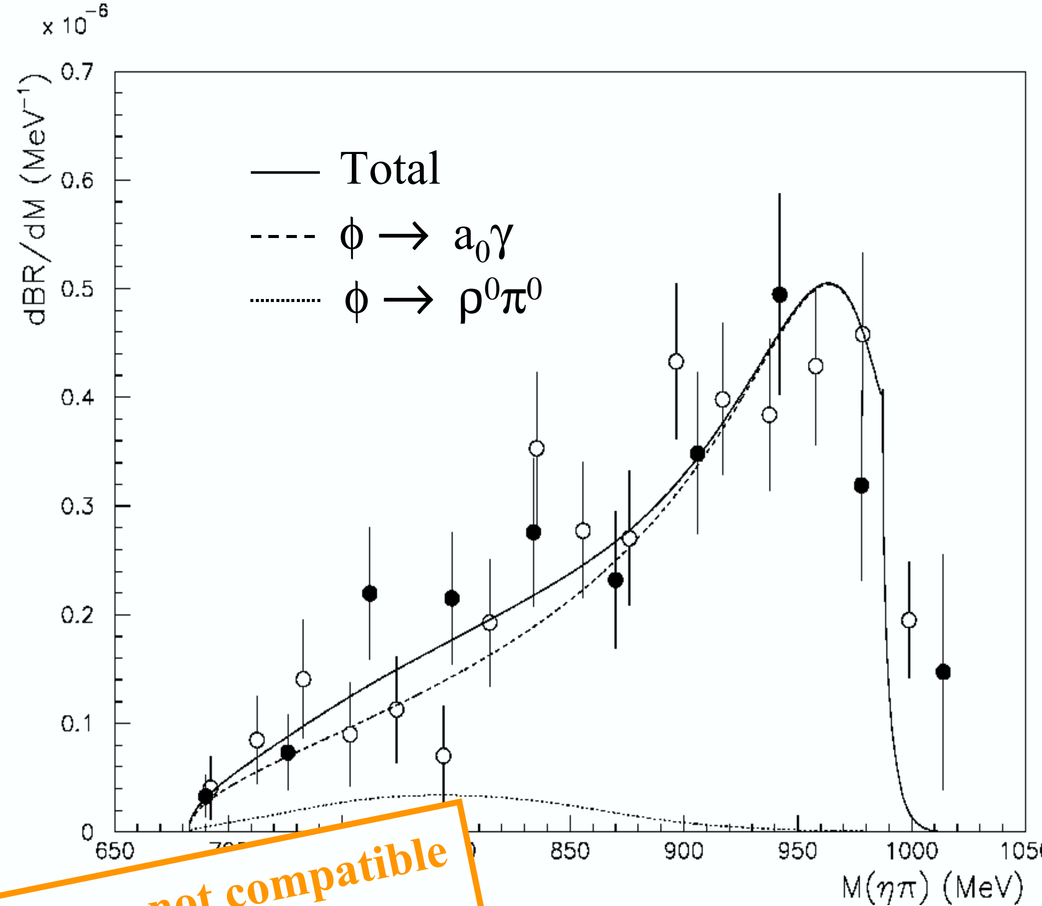
$N_{\eta\pi\gamma}$ = **197 ± 14** [$\eta \to \pi^+\pi^-\pi^0$]

BR($\phi \to \eta\pi^0\gamma$)=
($8.0 \pm 0.6_{stat} \pm 0.5_{syst}$) x 10^{-5}

[CMD-2 : ($9.0 \pm 2.4 \pm 1.0$) x 10^{-5}]
[SND : ($8.8 \pm 1.4 \pm 0.9$) x 10^{-5}]

Combined fit to the $M_{\eta\pi}$ spectrum:

- $\phi \to a_0\gamma \to \eta\pi^0\gamma$ **dominating**
- $\phi \to \rho^0\pi^0 \to \eta\pi^0\gamma$ **negligible**



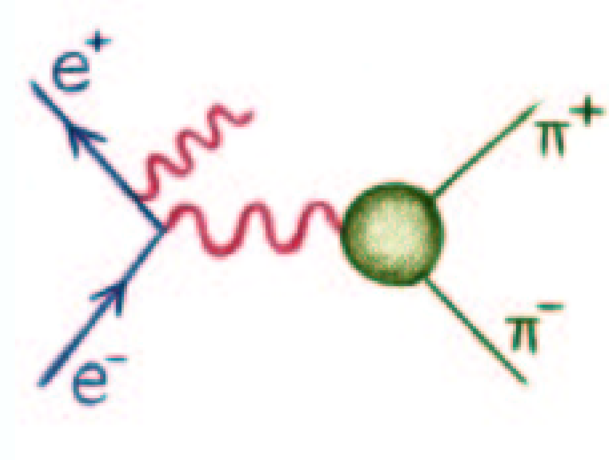
Parameters not compatible with qqqq model

Fit result: **Fixing the a_0 mass to PDG**

- $g^2(a_0KK)/4\pi$ = 0.40 ± 0.04 GeV^2
- $g(a_0\eta\pi)/g(a_0KK)$ = 1.35 ± 0.09
- BR($\phi \to a_0\gamma \to \eta\pi^0\gamma$) = $(7.4 \pm 0.7)10^{-5}$

Hadronic cross section

- KLOE can measure $\sigma(e^+e^- \rightarrow \text{hadrons})$ using the radiative return, following a complementary approach with respect to the standard energy scan:

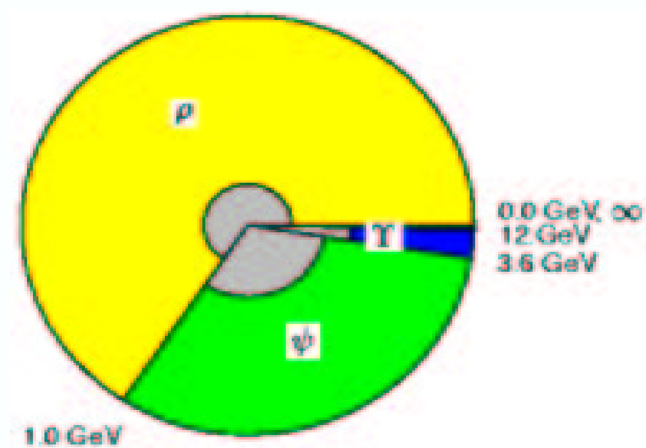


$$\mathbf{d\sigma(\pi\pi\gamma)/dM_{\pi\pi}^2 = R_\pi(M_{\pi\pi}^2,\theta_0)\times\sigma(\pi\pi,M_{\pi\pi}^2)}$$

with $(2m_\pi)^2 < M_{\pi\pi}^2 < (M_\phi)^2$ $[0.08 \rightarrow 1\ \text{GeV}^2]$

- ~ 70% of δa_μ^{had} (**5000** $\times 10^{-11}$) comes from this interval of $M_{\pi\pi}^2$

- knowledge of ISR function and rad cor (especially FSR) is essential → EVA Monte Carlo

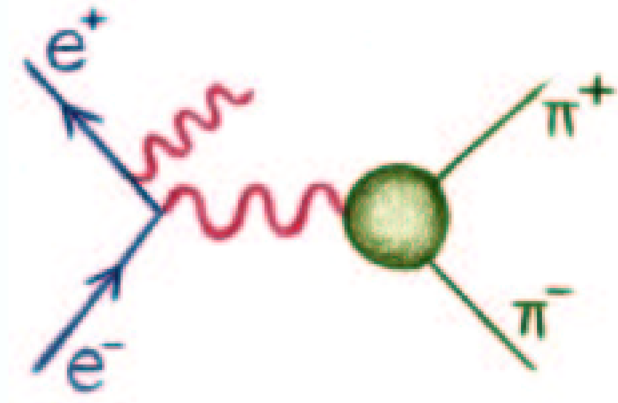


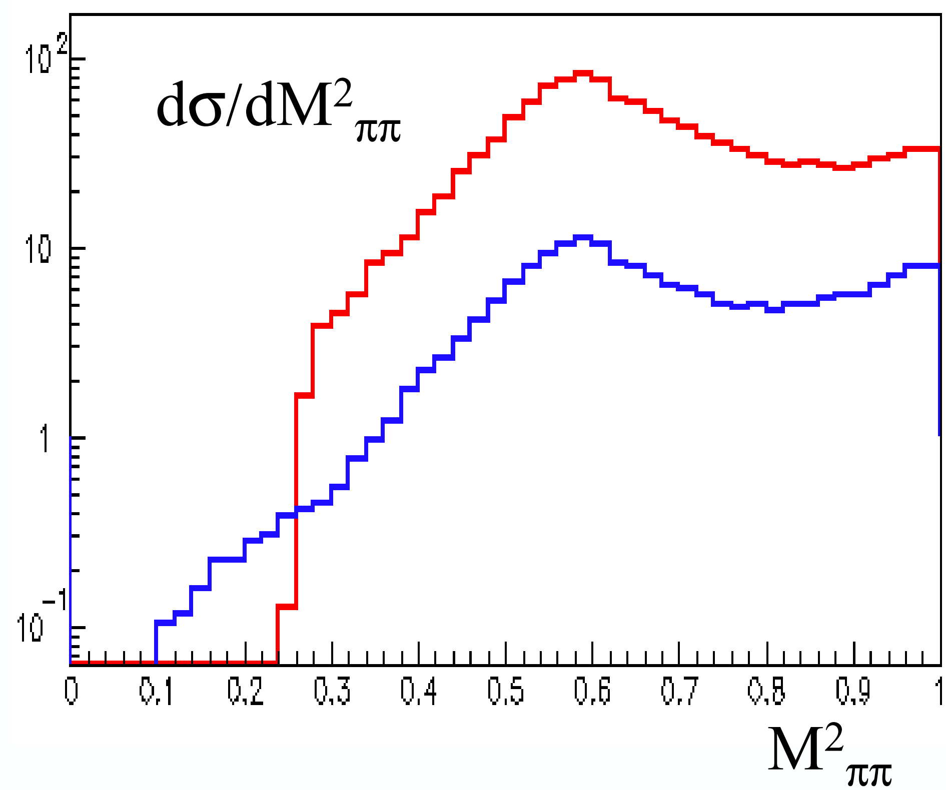
Hadronic cross section

Two tracks from IP, cut on θ_γ:

1) large angle $55^\circ < \theta_\gamma < 125^\circ$
- γ in the calorimeter
- larger contribution from FSR
- all $M^2_{\pi\pi}$ spectrum accessible

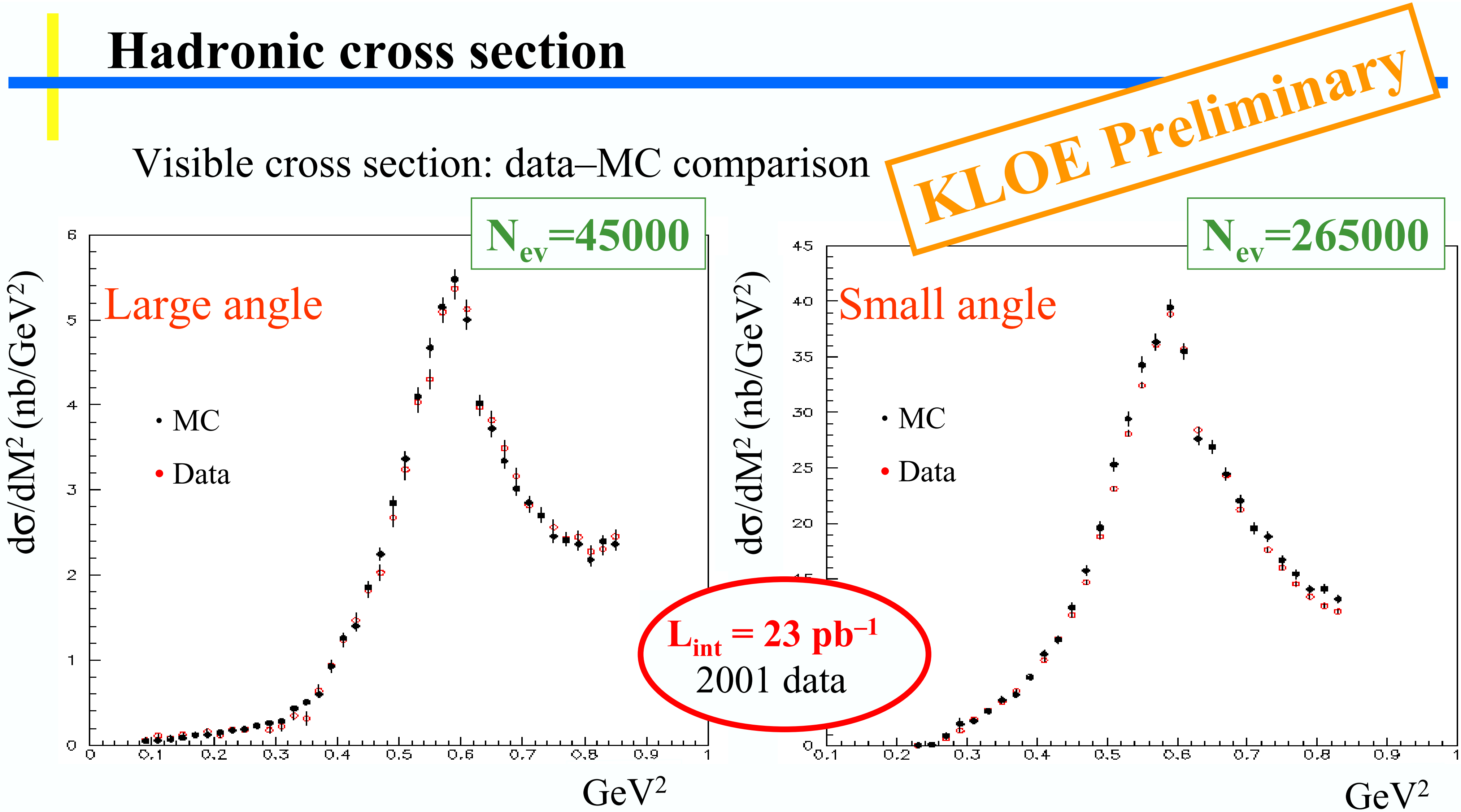
2) small angle $\theta_\gamma < 15^\circ$ or $\theta_\gamma > 165^\circ$
- no γ required
- larger σ (21 vs 3 nb)
- less FSR
- acceptance loss
  $\rightarrow M^2_{\pi\pi}$ min $> \pi\pi$ threshold





Hadronic cross section

Visible cross section: data–MC comparison



✓ KLOE 2001 data are enough to measure $\sigma(e^+e^- \to \pi^+\pi^-)$ with a statistical uncertainty of ~ 0.15% for small angle sample and ~ 0.3% for large angle sample

✓ The new ISR NLO generator from Kühn et al. (PHOKARA, α, α^2) improves the theoretical description of ISR (δ~0.5%)

Fit to the pion form factor from $\pi^+\pi^-\gamma$ at small angle

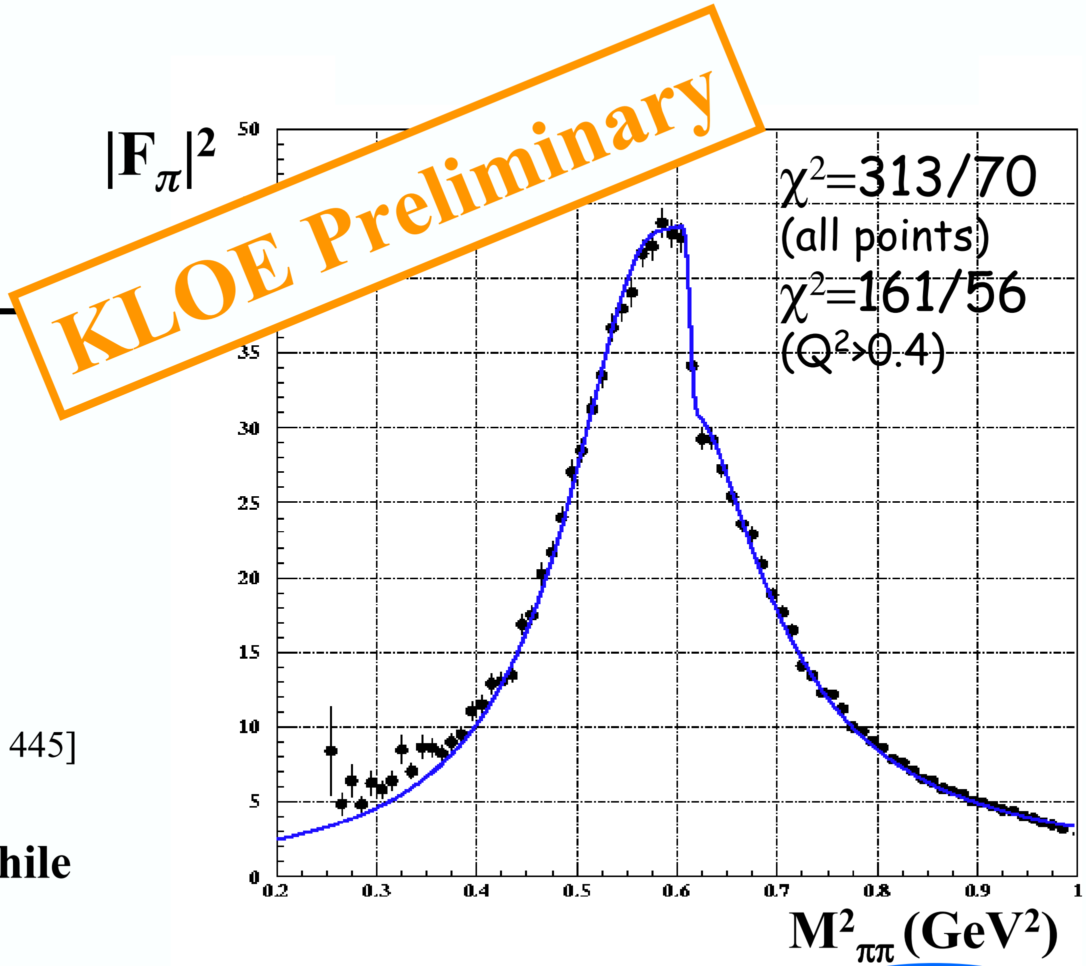
$$|F_\pi|^2 = \frac{d\sigma(\pi\pi\gamma)}{d\sigma(\pi\pi\gamma, F_\pi = 1)}$$

At small angle interference with FSR can be neglected.

$|F_\pi|^2$ extracted from data fitted with:

$$F_\pi(Q^2) = \frac{BW_\rho \dfrac{(1+\alpha BW_\omega)}{1+\alpha} + \beta BW_{\rho'}}{1+\beta}$$

[J.H.Kuehn and A. Santamaria, Zeit. F. Physik C48 (1990), 445]



m_ρ Γ_ρ α β **are free parameter of the fit, while**
m_ω Γ_ω $m_{\rho'}$ $\Gamma_{\rho'}$ **are fixed to CMD-2 values**

L_{int} = 73 pb^{-1}
2001 data

Fit results:

M_ρ = **0.7726 ± 0.0005 GeV** Γ_ρ = **0.1437 ±0.0007 GeV**

α = **(1.48 ±0.12) •10^{-3}** β = **– 0.1473 ± 0.002**

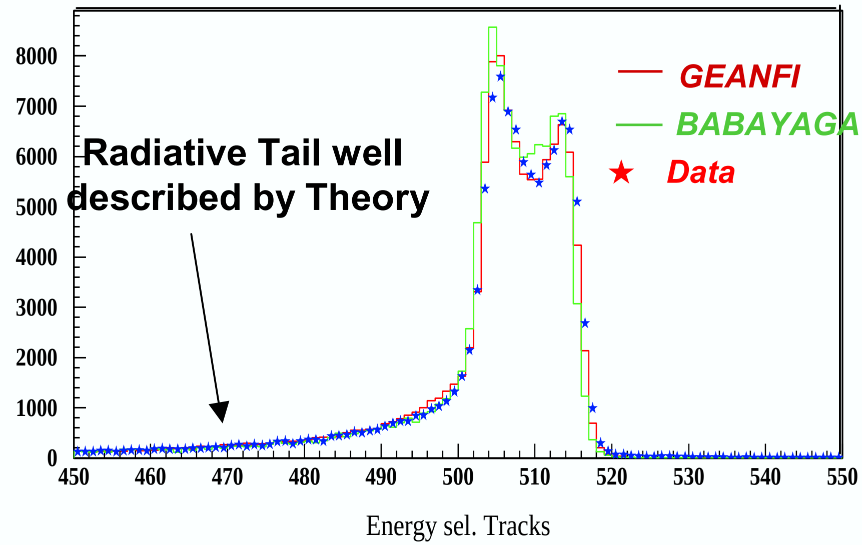
KLOE goals on the measurement of σ(had)

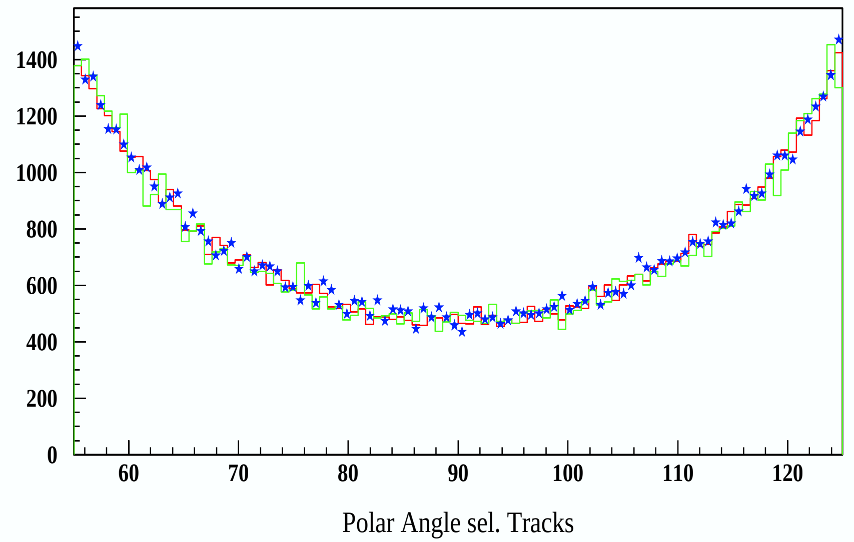
To measure **σ(had)** with 0.6 % error (0.26 ppm on **a_μ(had)**):

1) Comparable but fully independent measurement from CMD-2 while covering also low $M_{\pi\pi}$ region

2) Contributions to error:

- stat. negligible
- dL/L < 1% using VLAB, in progress comparison with γγ and $\mu^+\mu^-$
- acceptance calculation (EVA+ Phokara et al.) 0.5%
- TRK+VTX … already < 1%
- Now ≈2% or 1 ppm





θ_e(degrees)

Dynamics of the $\phi \rightarrow \pi^+\pi^-\pi^0$ decay

Fit to the Dalitz plot of the decay $\phi \rightarrow \pi^+\pi^-\pi^0$ in progress...

Fit function

$$|A|^2 = \left|\vec{p}^{\,+} \times \vec{p}^{\,-}\right|^2 \left|\sum_i A_i\right|^2$$

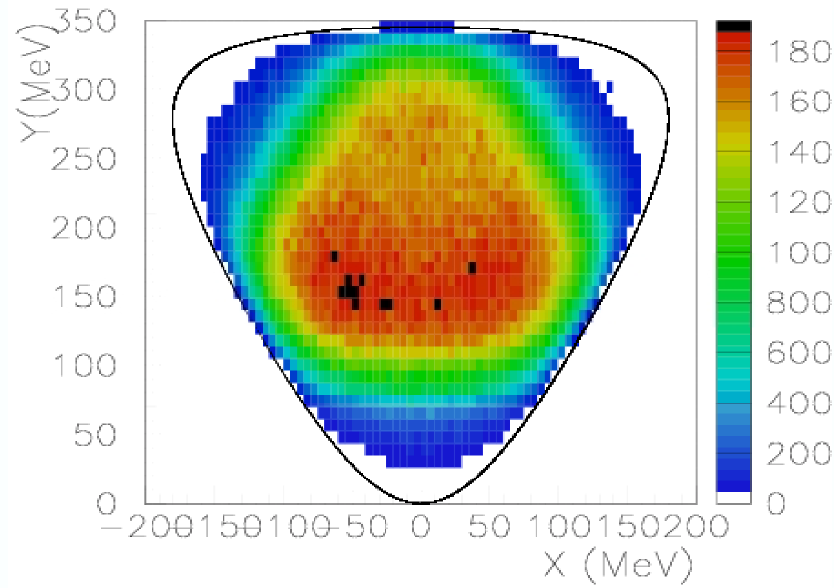
$$\sum_i A_i = A_{dir} + A_{\rho\pi} + A_{\omega\pi}$$

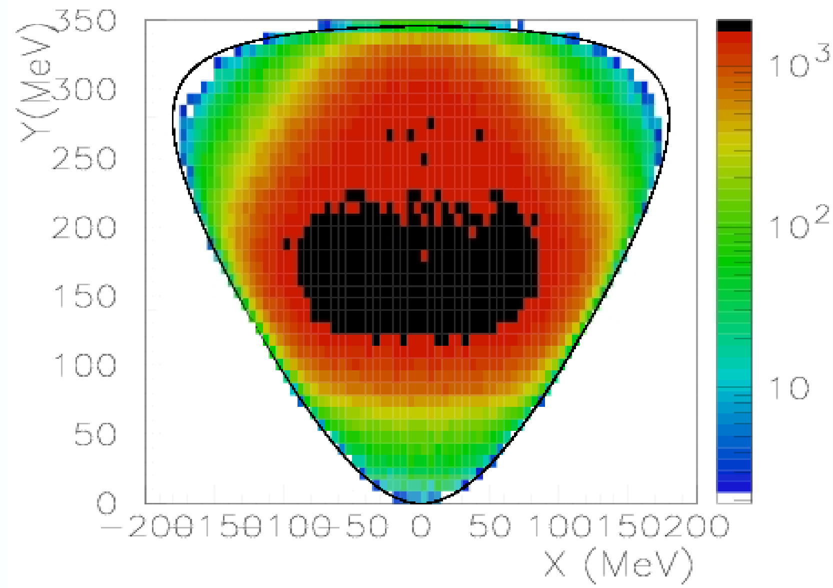
The two **main terms** are (the $\omega\pi$ term is not relevant):

$$A_{dir} = C a_d e^{i\phi} \qquad A_{\rho\pi} = \sum_{k=1}^{3} \frac{1}{q_k^2 - m_k^2 + i m_k \Gamma_k(q_k^2)}$$

$$\Gamma_k(q_k^2) = \Gamma_k \left[\frac{p_\pi(q_k^2)}{p_\pi(m_k^2)}\right]^3 \left(\frac{m_k^2}{q_k^2}\right)^{\lambda/2}$$

$Y=(E_{\pi 0} - M_{\pi 0})$ $X=(E_{\pi +} - E_{\pi -})/\sqrt{3}$





Dynamics of the $\phi \to \pi^+\pi^-\pi^0$ decay

Tested on a sample of 20 pb^{-1} (2000 data)

- Dalitz plot of 1.98×10^6 events after selection
- Bins of 8.75 x 8.75 MeV (350 MeV / 40)
- Number of effective bins = 1874

KLOE Preliminary

$\chi 2$ = 1947(1874-8)

Free parameters are:

1. An overall factor C
2. a_d and ϕ_d
3. $M(\rho^0)$ $\Delta M_{0,\pm}$ ΔM_{+-}
4. Γ_ρ
5. $a_{\omega\pi}$

$$a_d = 0.093 \pm 0.011 \pm 0.015$$
$$\phi_d = 2.45 \pm 0.09 \pm 0.11 \text{ rad}$$

$$M(\rho^0) = 775.86 \pm 0.57 \pm 0.67 \text{ MeV}$$
$$\Delta M_{0,\pm} = -0.54 \pm 0.34 \pm 0.68 \text{ MeV}$$
$$\Delta M_{+-} = 0.73 \pm 0.39 \pm 0.67 \text{ MeV}$$
$$\Gamma_\rho = 145.2 \pm 1.2 \pm 1.0 \text{ MeV}$$

Next year perspectives on 'prompt γ' physics

- **Analysis of new data ×10 statistics, fit all parameters**
- **BR($\phi \to \eta'\gamma$) with $\pi^+\pi^-7\gamma$ final state**
- **Hadronic cross-section $\sigma(e^+e^- \to \pi^+\pi^-)$** in the $2m_\pi < \sqrt{s} < m_\phi$ range
- **Dynamics of the $\phi \to \pi^+\pi^-\pi^0$ decay** to extract the $\rho^+ \rho^- \rho^0$ parameters
- η **decays** [**6 x10^6 η tag in 2001 data**] :

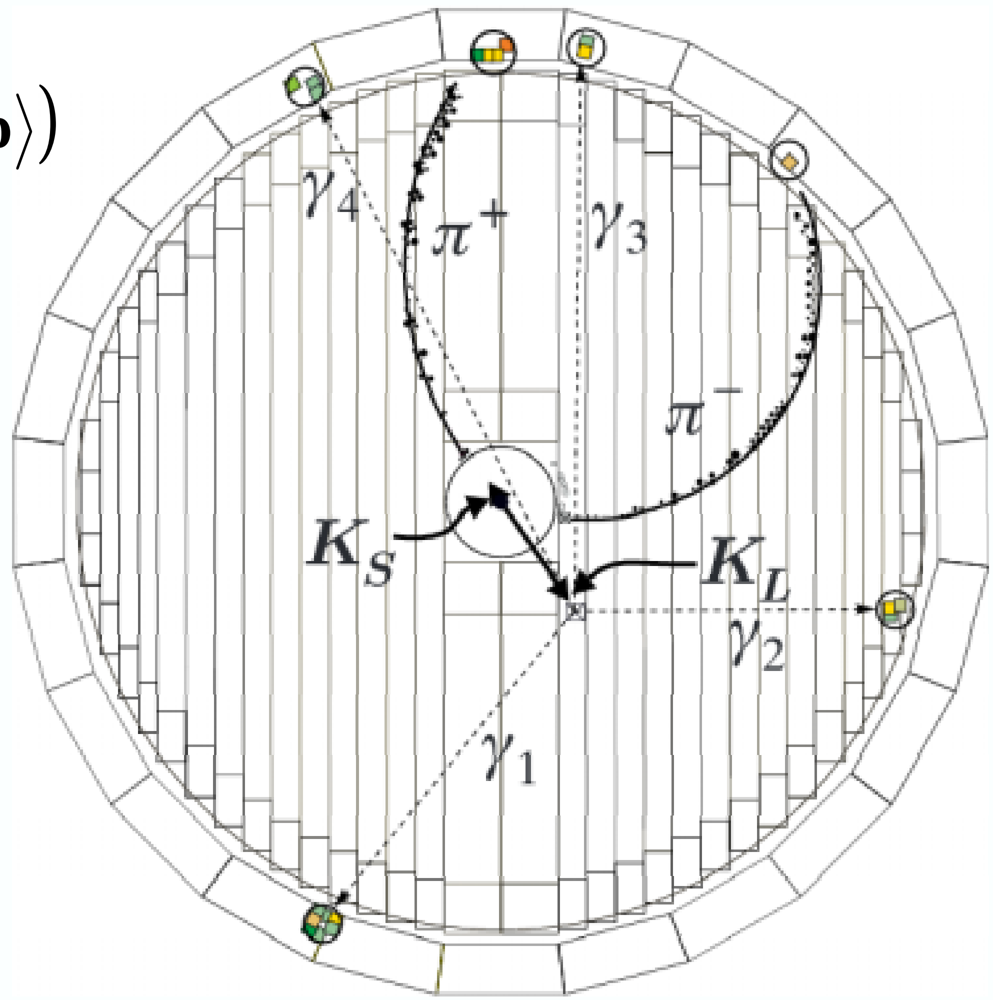
$\eta \to \gamma\gamma\gamma$	(test of C invariance)	
$\eta \to \pi^+\pi^-\gamma$	(photon spectrum)	Significant checks of χ_{PT}
$\eta \to \pi^+\pi^-\pi^0$ / $\pi^0\pi^0\pi^0$	(Dalitz plot slopes)	
$\eta \to \pi^0\gamma\gamma$	(branching ratio)	

Neutral kaon production

Example of $\phi \rightarrow$ $K_S \rightarrow \pi^+\pi^-$
$K_L \rightarrow \pi^0\pi^0$

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

$$|i\rangle \approx \frac{1}{\sqrt{2}}\left(|K_L,\mathbf{p}\rangle|K_S,-\mathbf{p}\rangle - |K_L,-\mathbf{p}\rangle|K_S,\mathbf{p}\rangle\right)$$



Tagging: pure K_S and K_L beams

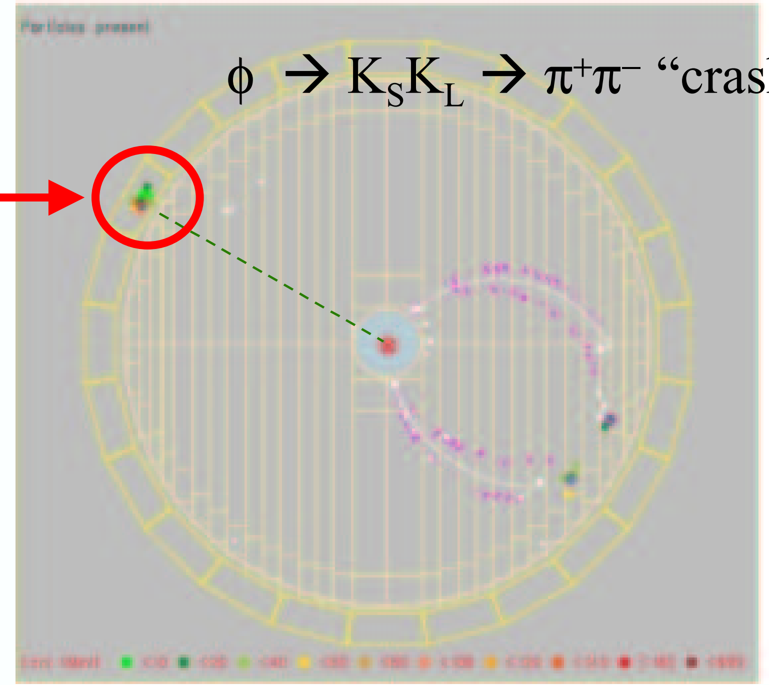
- → analysis of kaon decays
- → Re(ε '/ ε) with double ratio
- → kaon interferometry

K_S tagging

- Clean **K_S** tagging by time-of-flight identification of **K_L** interactions in the calorimeter
- K_L velocity in the ϕ rest frame

$$\beta^{*} \sim 0.218$$

- Tagging efficiency **$\varepsilon_{tag,total} \sim 30\%$**

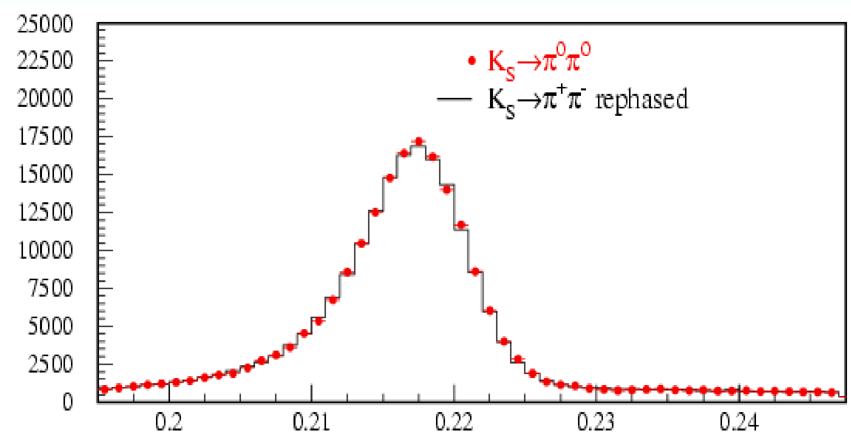


KLOE has now about **$6\ 10^7$ tagged K_S.**
All channels are accessible.
Results from 2000 data (**$5.4\ 10^6$ tagged K_S**) on:

(1) $R = \Gamma(K_S \rightarrow \pi^+\pi^-) / \Gamma(K_S \rightarrow \pi^0\pi^0)$
(2) $BR(K_S \rightarrow \pi^{\pm} e^{\pm} \nu)$

Phys. Lett. **B 538** (2002), 21

Phys. Lett. **B 535** (2002), 37

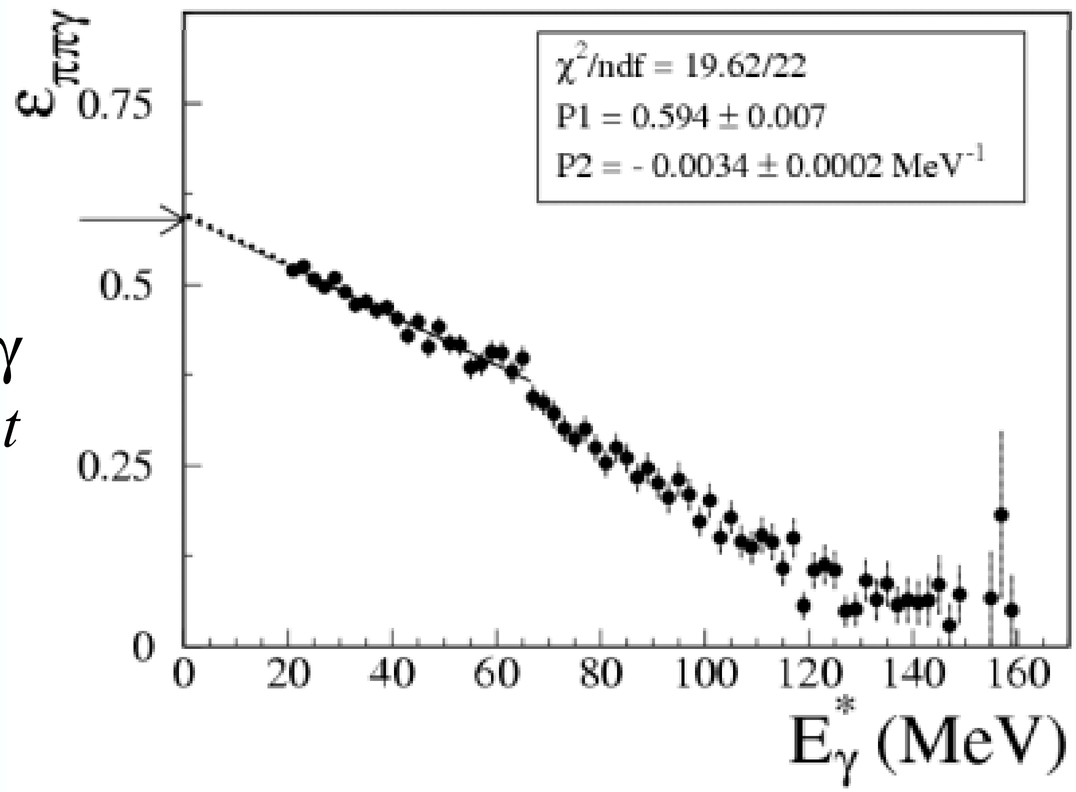


β^* distribution of "K_L crash"

$\Gamma(K_S \rightarrow \pi^+\pi^-(\gamma)) / \Gamma(K_S \rightarrow \pi^0\pi^0)$: selection

1. $K_S \rightarrow \pi^+\pi^-(\gamma)$

- *two tracks from I.P.*
  + acceptance cuts
- no cut on $M(\pi\pi)$, no request on γ
  $\rightarrow$ *fully inclusive measurement*
- $\varepsilon_{\pi\pi\gamma}(E_\gamma^*)$ from MC folded to theoretical γ spectrum

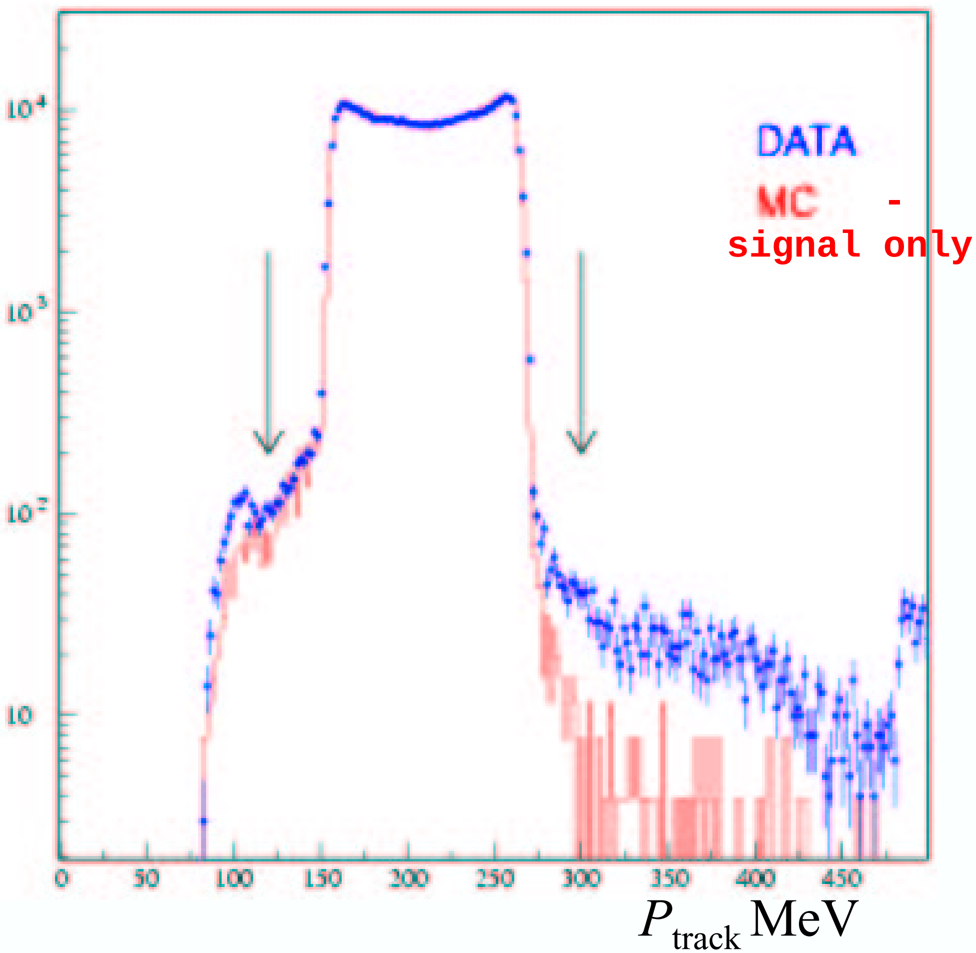


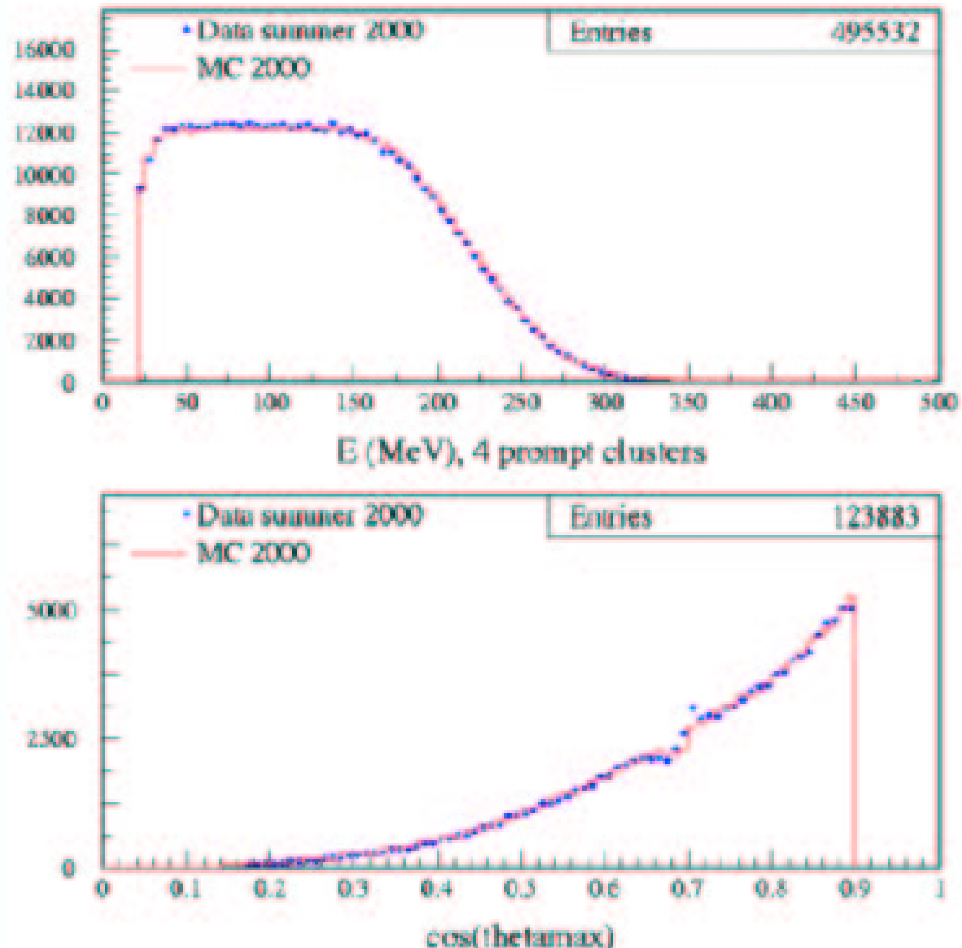
2. $K_S \rightarrow \pi^0\pi^0$

- *neutral prompt cluster* : E_γ>20 MeV and (T-R/c) < $5\sigma_t$
- *at least 3 neutral prompt clusters* : $\pi^0 \rightarrow e^+e^-\gamma$ included

$\Gamma(K_S \to \pi^+\pi^-(\gamma)) / \Gamma(K_S \to \pi^0\pi^0)$: data quality

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





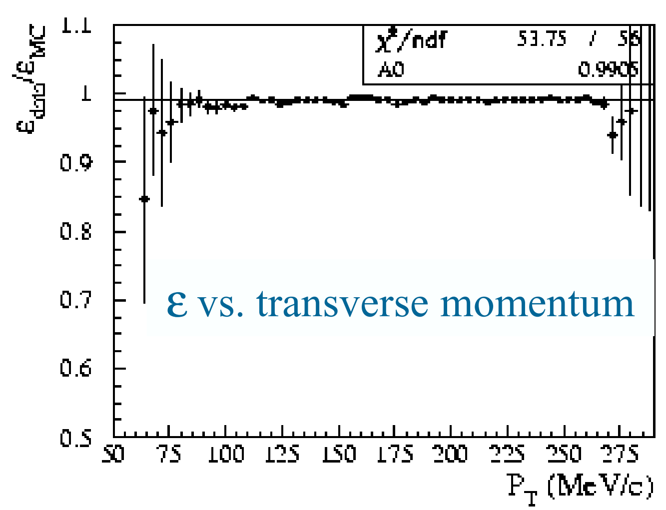
$\text{Acc}\times\varepsilon_{tot} = (57.6 \pm 0.1 \pm 0.1)\%$

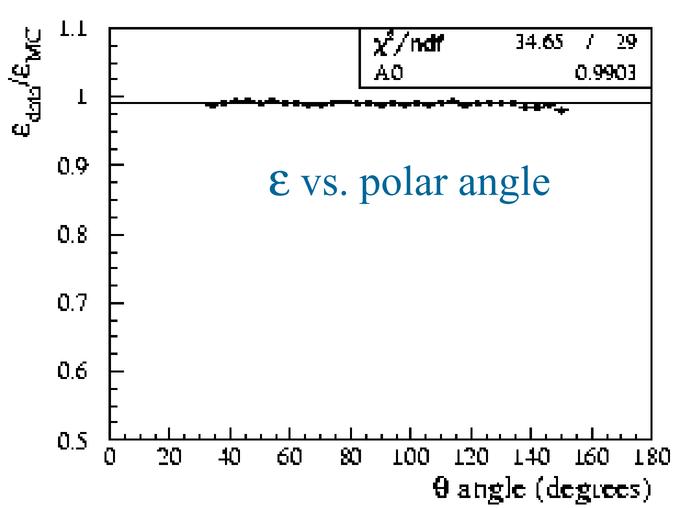
$\text{Acc}\times\varepsilon_{tot} = (90.05 \pm 0.05 \pm 0.17)\%$

$\Gamma(K_S \rightarrow \pi^+\pi^-(\gamma)) / \Gamma(K_S \rightarrow \pi^0\pi^0)$: efficiencies

$K_S \rightarrow \pi^+\pi^-$ control data sample

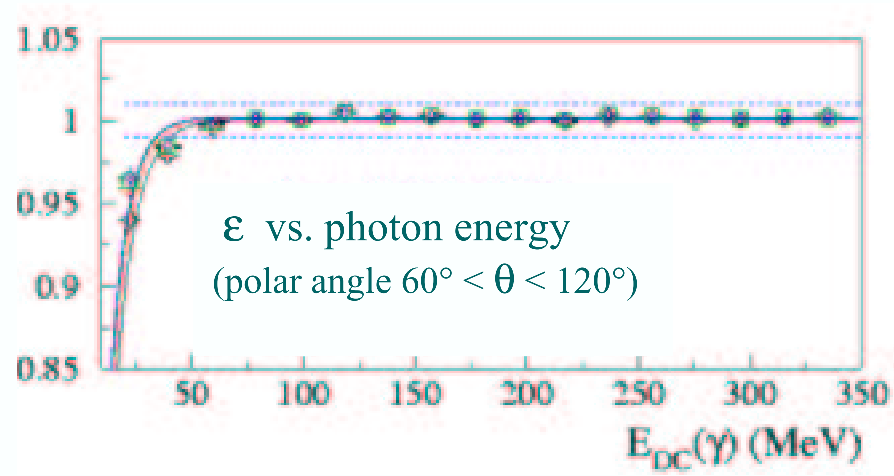
Tracking efficiency: **Data/MC ratio**

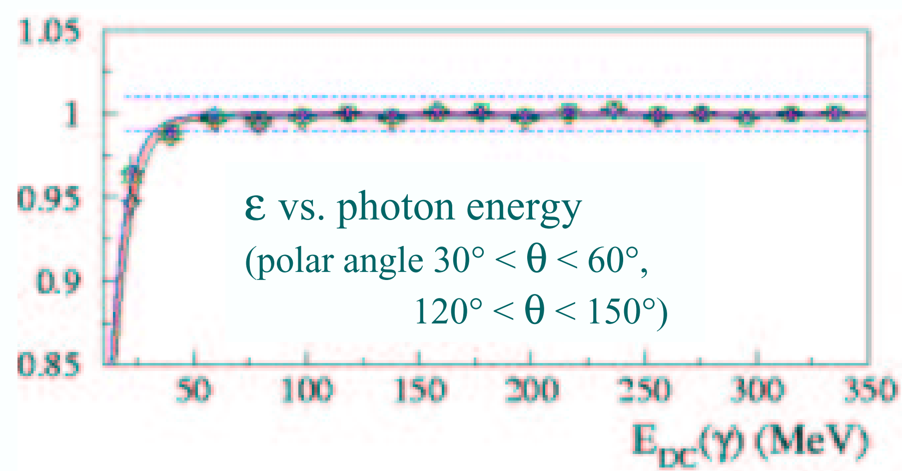




$\phi \rightarrow \pi^+\pi^-\pi^0$ control data sample

Photon detection efficiency: **Data/MC ratio**

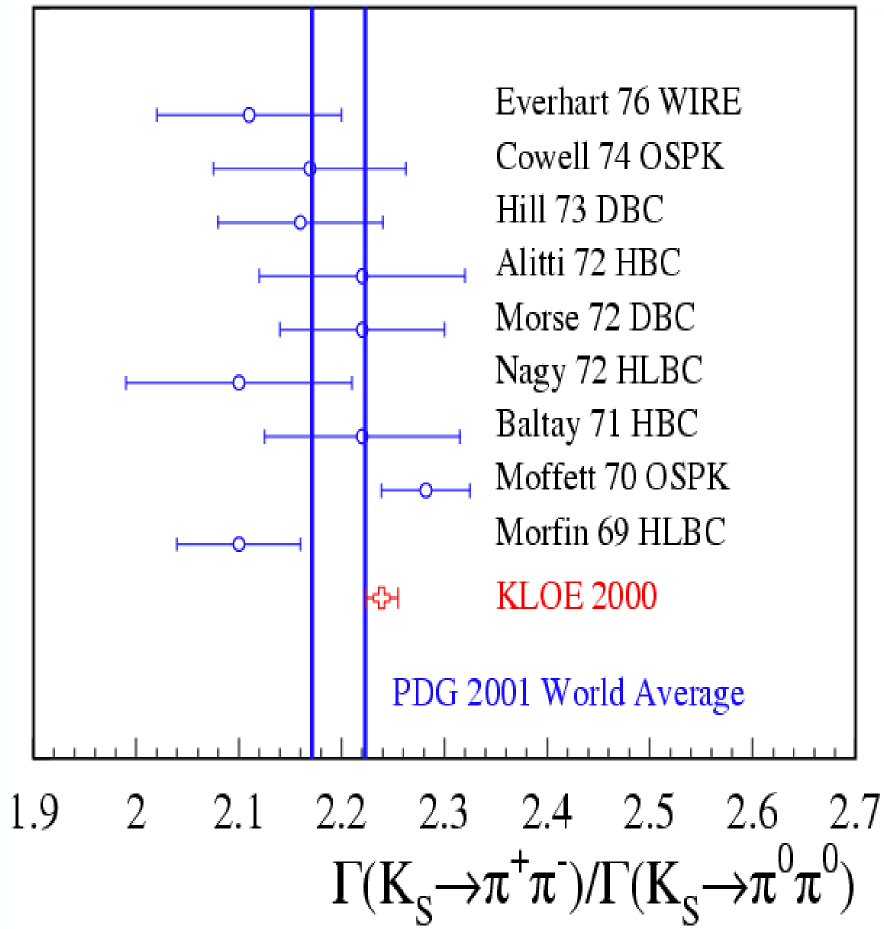




$\Gamma(K_S \to \pi^+\pi^-(\gamma)) / \Gamma(K_S \to \pi^0\pi^0)$: results

(t_0 and trigger efficiencies from $K_S \to \pi^+\pi^-$, $K_L \to \pi^+\pi^-\pi^0$, $\phi \to \pi^+\pi^-\pi^0$)

KLOE 2000 data	**$2.236 \pm 0.003_{stat} \pm 0.015_{syst}$**	**($17\ pb^{-1}$)**
PDG 2001	2.197 ± 0.026	(without clear indication of $E\gamma$)



Contrib. to systematic error	%
$K_S \to \pi^0\pi^0 / K_S \to \pi^+\pi^-$ tag	0.55
photon counting	0.20
trigger	0.23
tracking	0.26
Overall systematic error	0.68

NB: efficiencies estimated using data control samples (statistically limited)

Goal = reach 0.1% systematic uncertainty [$< 2 \cdot 10^{-4}$ on $Re(\varepsilon'/\varepsilon)$] + photon spectrum

Semileptonic decays: $K \to \pi l \nu$

$A(K^0 \to l^+) = a + b \quad A(\bar{K}^0 \to l^-) = a^* - b^* \quad (\Delta S = \Delta Q)$

$A(K^0 \to l^-) = c + d \quad A(\bar{K}^0 \to l^+) = c^* - d^* \quad (\Delta S = -\Delta Q)$

(a,c = CPT conserving   b,d = CPT violating)

CPT test ($\Delta S = \Delta Q$)

- $A = (\Gamma^+ - \Gamma^-)/(\Gamma^+ + \Gamma^-)$

$\to A_S - A_L = 4\mathrm{Re}\delta$

(no direct measurement)

- CPLEAR: $(2.9 \pm 2.7) \times 10^{-4}$
- KLOE with 10^4 pb^{-1}

$[\delta = (\varepsilon_S - \varepsilon_L)/2]$

$\Delta S = \Delta Q$ test (CPT conserved)

- $(\Gamma^+_S + \Gamma^-_S)/(\Gamma^+_L + \Gamma^-_L) = 1 + 4\mathrm{Re}(c/a)$

$$\to 4\mathrm{Re}(c/a) = \frac{BR(K_S \to \pi e \nu)\ \tau_L}{BR(K_L \to \pi e \nu)\ \tau_S} - 1$$

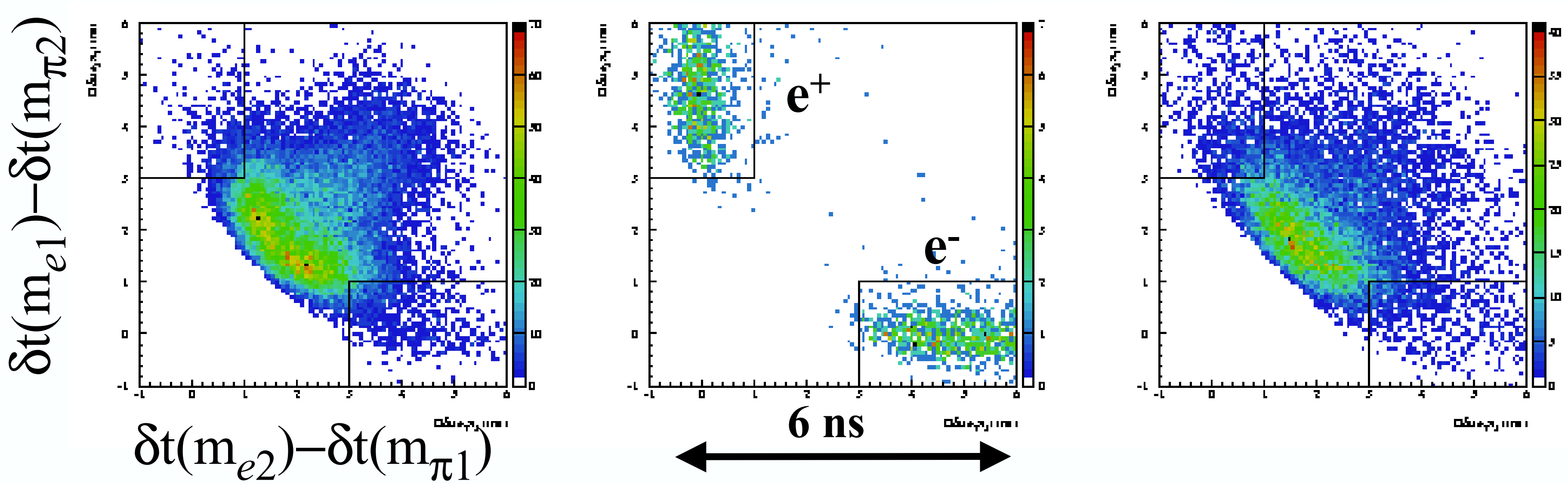
- CPLEAR: $(-1.8 \pm 6.1) \times 10^{-3}$ (d=0 assumed)
- KLOE with 70 pb^{-1} ($\Delta BR(K_S \to \pi e \nu) \sim 2\%$)

$K_S \rightarrow \pi e \nu$: selection

- charged vertex at IP → two tracks ($M_{\pi\pi} \neq M_K$)
- both tracks associated to calorimeter clusters

- Time of flight e/π identification ($\Delta t \sim 2$ ns) : $\delta t(m) = t_{cluster} - t.o.f.$ calculated with mass hyphotesis m
- Sign of the charge is determined → semileptonic asymmetry accessible

MC $K_S \rightarrow \pi^+\pi^-$ | MC $K_S \rightarrow \pi e \nu$ | Data 2000

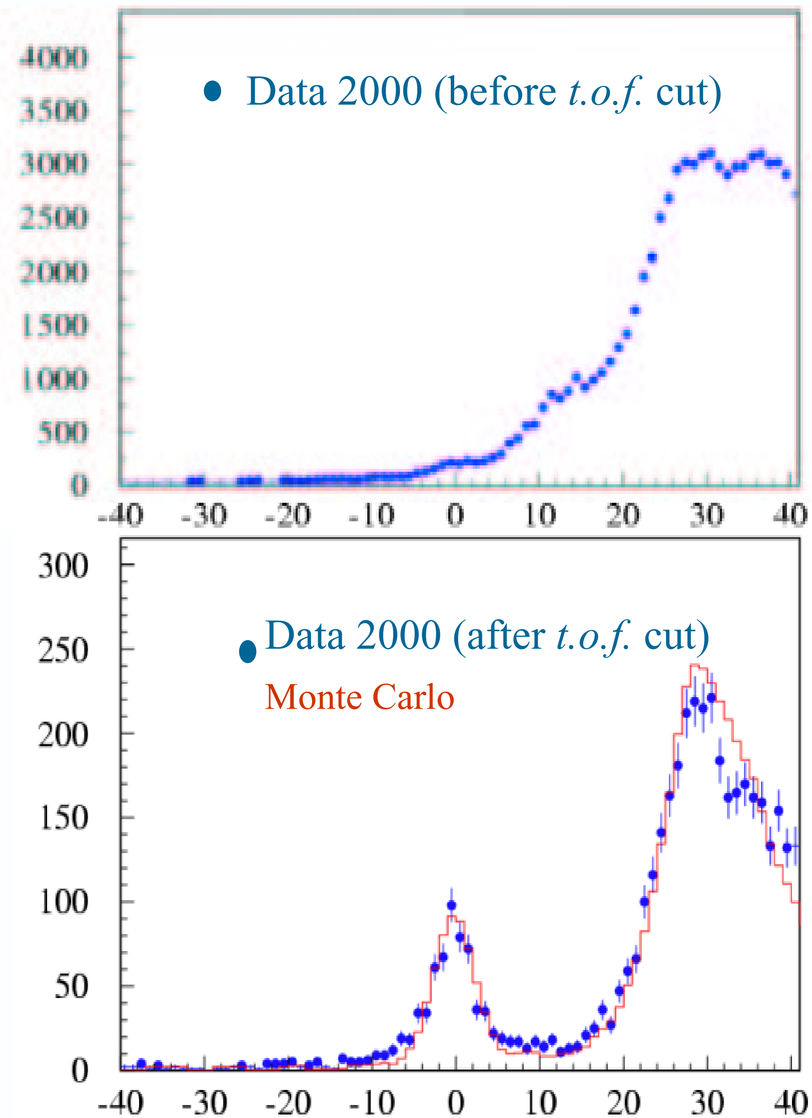


$K_S \to \pi e \nu$: final selection

Kinematic closure of the event:

$P_\nu = P_{miss} = P_K - P_\pi - P_e$

- **t_0, track-cluster, and trigger efficiencies from data**:
  - $K_L \to \pi e \nu$ near origin
  - $\phi \to \pi^+\pi^-\pi^0$, $K_S \to \pi^+\pi^-$
- **Overall selection efficiency:** $(21.9 \pm 0.7)\%$
- **Fit to E_{miss}-P_{miss} with MC shape of signal and background**
- **Normalization to $K_S \to \pi^+\pi^-$ decays**



E_{miss}-P_{miss} (MeV)

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

❖ Fit Signal+Background MC shape:
627 ± 30 events

❖ Correct for efficiencies, normalize to $K_S \to \pi^+\pi^-$

- **KLOE:** (17 pb^{-1})
  $(6.91 \pm 0.34_{stat} \pm 0.15_{syst})\ 10^{-4}$

- Using PDG information (c=0 hyp.)
  $BR(K_L \to \pi e \nu)(\Gamma_L/\Gamma_S) = (6.704 \pm 0.071)\ 10^{-4}$

- CMD-2 (75 events) $= (7.2 \pm 1.4)\ 10^{-4}$

Contributions to total error	%
Statistics	**4.9**
Tracking + vertex efficiency	1.4
Cluster, t_0 , trigger	0.7
TOF selection efficiency	0.9
Tag efficiency	0.7
Total	**5.3**

15 times more data already on tape → **A_s with 1% error**

Non leptonic decays: direct CP violation

The experimental quantity most sensitive to ε' is the double ratio :

$$R = \left|\frac{\eta_{+-}}{\eta_{00}}\right|^2 = \frac{\Gamma(K_L \to \pi^+\pi^-)\,\Gamma(K_S \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^+\pi^-)\,\Gamma(K_L \to \pi^0\pi^0)} = 1 + 6\,\mathrm{Re}(\varepsilon'/\varepsilon)$$

- At *fixed target* experiments cancellation of systematics between K_S and $K_L \to \pi^+\pi^-$ ($\pi^0\pi^0$) decays (same detector, same fiducial volume)
- No absolute normalization needed between K_S (K_L) different decays

Present results unambiguosly establish $\varepsilon' \neq 0$:

E731	$(7.4 \pm 5.2_{stat} \pm 2.9_{syst})10^{-4}$
NA31	$(23.0 \pm 6.5)10^{-4}$
KTeV	$(\mathbf{20.7 \pm 1.5}_{\mathbf{stat}} \pm \mathbf{2.4}_{\mathbf{syst}})10^{-4}$
NA48	$(\mathbf{14.8 \pm 2.2}_{\mathbf{stat+syst}})10^{-4}$

Non leptonic decays: direct CP violation

The experimental quantity most sensitive to ε' is the double ratio :

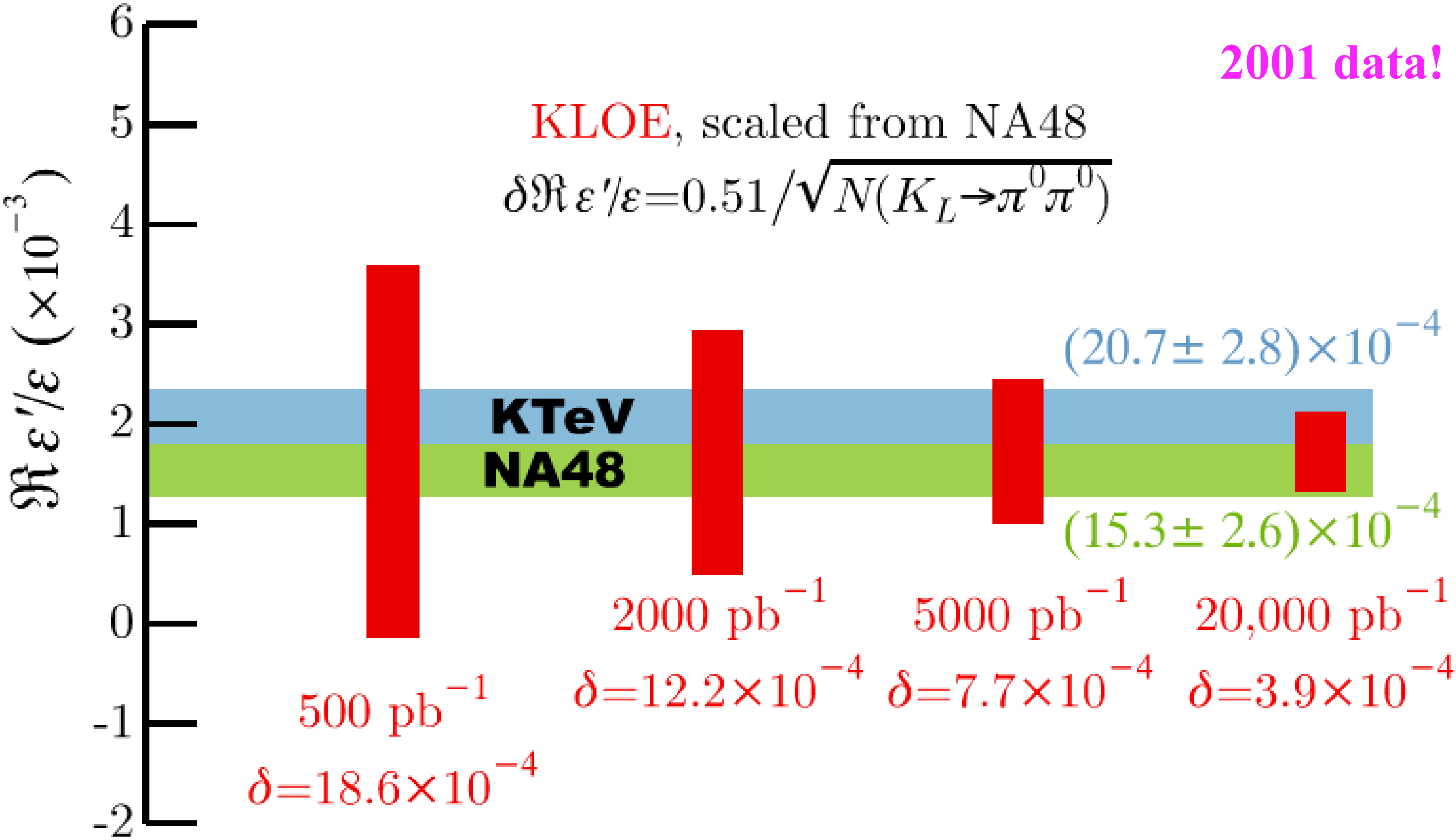
$$R = \left|\frac{\eta_{+-}}{\eta_{00}}\right|^2 = \frac{\Gamma(K_L \to \pi^+\pi^-)\,\Gamma(K_S \to \pi^0\pi^0)}{\Gamma(K_L \to \pi^0\pi^0)\,\Gamma(K_S \to \pi^+\pi^-)} = 1 + 6\,\mathrm{Re}(\varepsilon'/\varepsilon)$$

• Note: experiments measure *double ratio* to 0.1% and the *single ratios* to 1%

• KLOE aims at measuring each *single ratio* (K_L and K_S) to 0.1% using *tagging* (no abs. normalization, no background)

• Also observe quantum interference

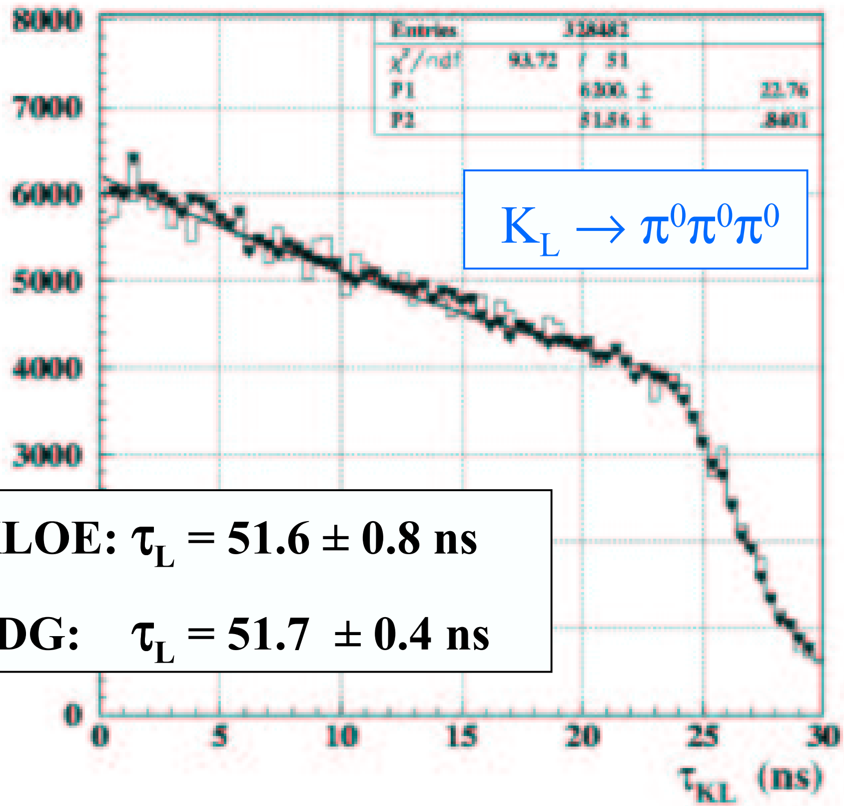
How far from CP?



2001 data sample: $K_L \rightarrow \gamma\gamma$ / $K_L \rightarrow \pi^0\pi^0\pi^0$

- Long distance contribution to the rare $K_L \rightarrow \mu^+\mu^-$ decay
- Predictions on $K_S \rightarrow \gamma\gamma$
- Relative uncertainty on BR($K_L \rightarrow \pi^0\pi^0\pi^0$) ~ 1.3%

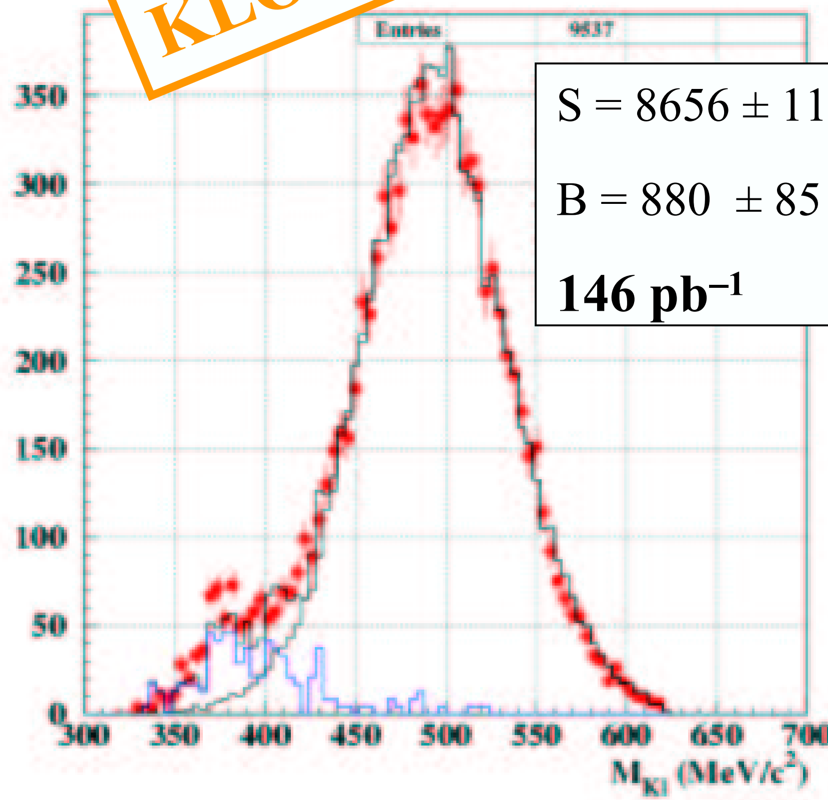
KLOE Preliminary



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

KLOE: τ_L = 51.6 ± 0.8 ns

PDG: τ_L = 51.7 ± 0.4 ns



S = 8656 ± 112

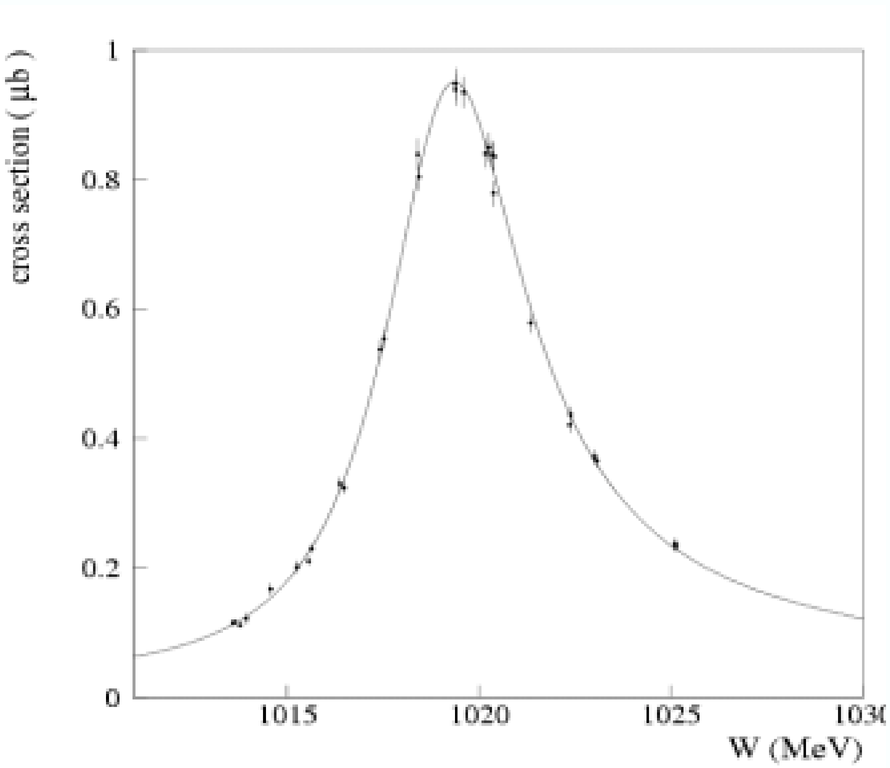
B = 880 ± 85

146 pb^{-1}

$R = (2.84 \pm 0.037_{stat} \pm 0.034_{syst})10^{-3}$

2001 energy scan: K_S mass

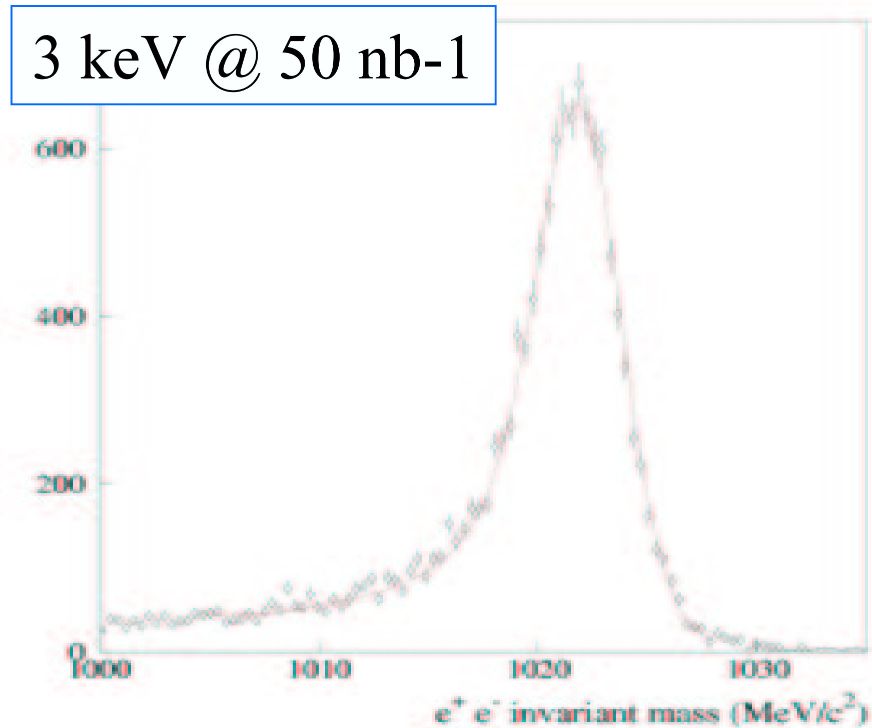
11 energy points, about **500** nb^{-1}



$\phi \rightarrow K_S K_L$, $K_S \rightarrow \pi^+\pi^-$

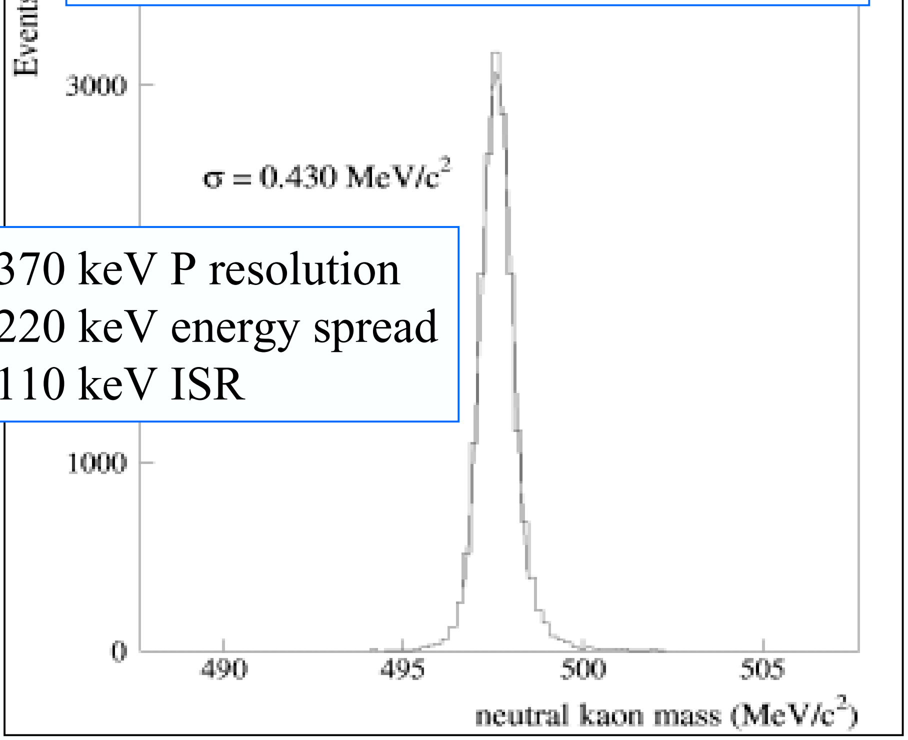
$$M^2_K = W^2/4 - P^2_K$$

- **W** from e^+e^- invariant mass spectrum
- Absolute calibration from ϕ - scan using the g-2 depolarizing resonance measurement at Novosibirsk
- $\mathbf{P_K}$ from $K_S \rightarrow \pi^+\pi^-$ ($\delta M/M \sim 0.05\ dP/P$)



2001 energy scan: K_S mass

Single event Mass Resolution



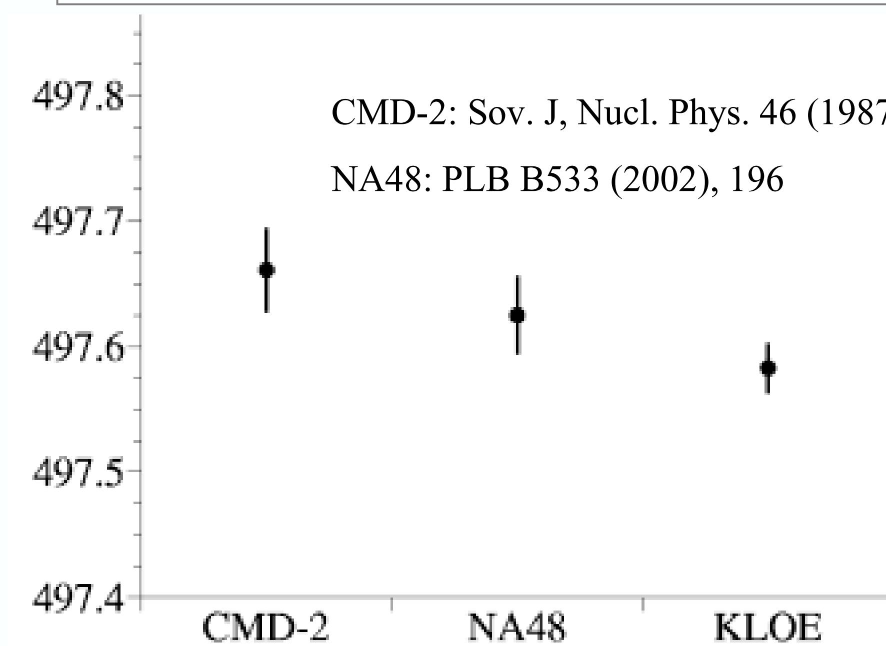
370 keV P resolution
220 keV energy spread
110 keV ISR

Contributions to sys. error	keV
P scale	6
ISR	7
Mφ (KLOE)	11
Mφ (CMD-2)	11
TOTAL	20

KLOE Preliminary

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

Comparison with existing measurements

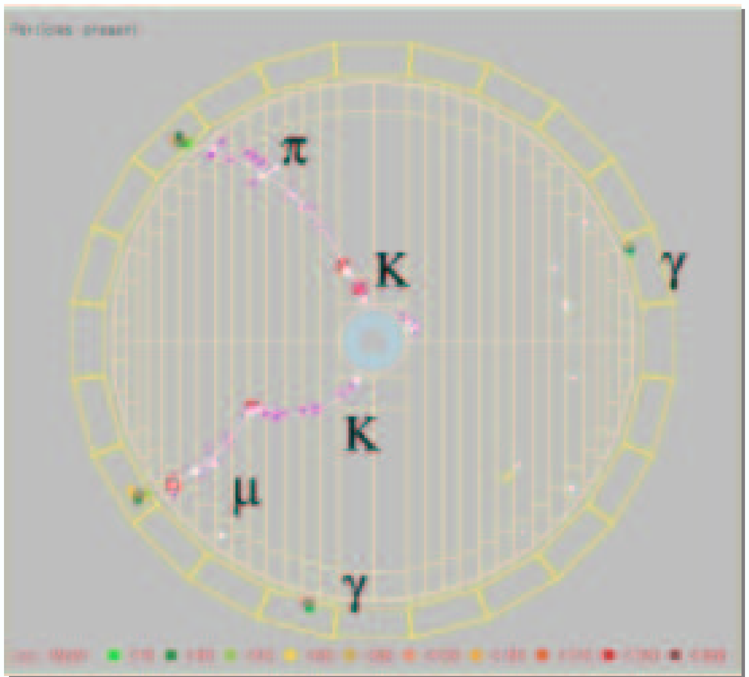


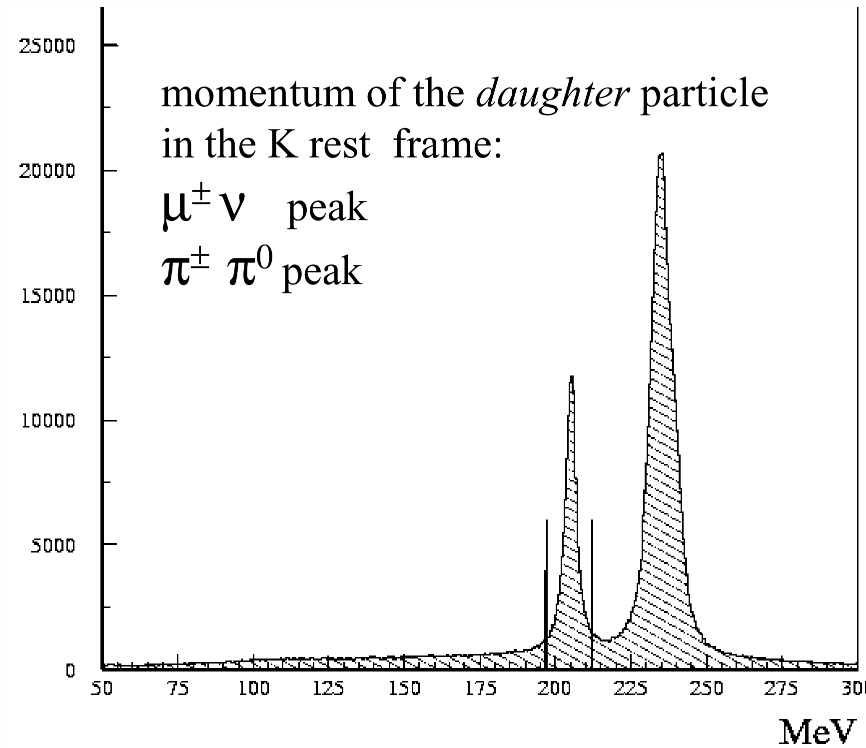
CMD-2: Sov. J, Nucl. Phys. 46 (1987), 630

NA48: PLB B533 (2002), 196

2001 data sample: charged kaons

KLOE *unique* feature is *tagging***:** observe $K^+ \rightarrow \pi^+\pi^0$ or $K^+ \rightarrow \mu^+\nu$ $\Rightarrow$ 6×10^5 tags/pb^{-1}





- $K \rightarrow \pi^0 e^\pm \nu$: improve experimental error on Vus (0.59% BR and τ, 0.22% form factors, 0.86 % theo) ; σ_{stat} (KLOE) ~ 0.25% with 200 pb^{-1}
- $K \rightarrow 3\pi$: Dalitz plot parameters

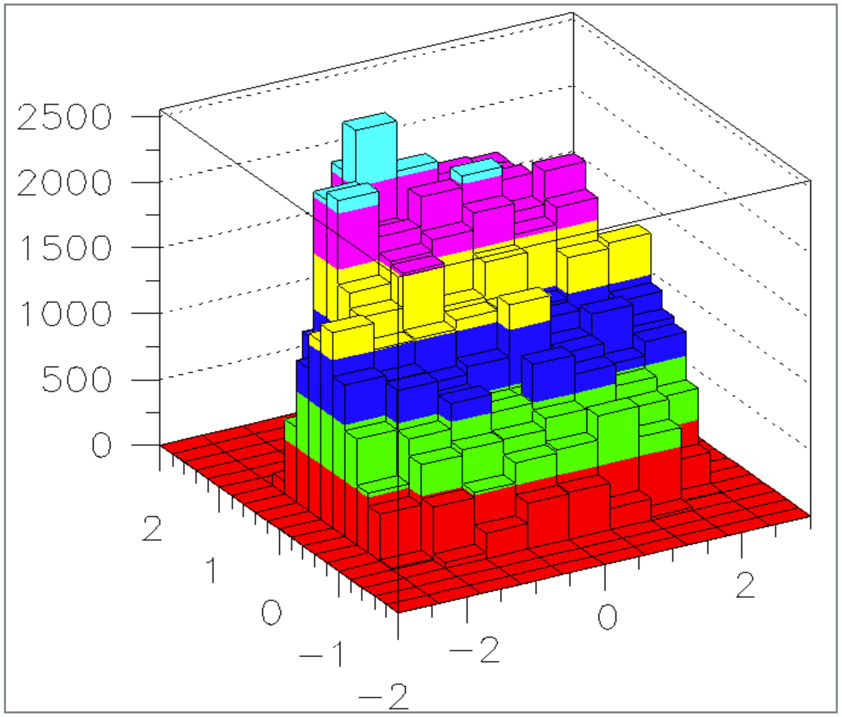
Dalitz plot on $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ decays

$s_0 = \Sigma_i s_i/3 = (m_K^2 + m_\pi^2 + 2m_{\pi^\circ}^2)/3 \quad \Rightarrow \quad X = (s_1 - s_2)/m_\pi^2$

$s_i = (P_K - P_i)^2 \quad i = 1,2,3 \qquad Y = (s_3 - s_0)/m_\pi^2$

$$\mathbf{F}(X,Y;g,h,k) = 1+\mathbf{g}Y+\mathbf{h}Y^2+\mathbf{k}X^2$$

CP ASYMM. $(g_+ - g_-) / (g_+ + g_-)$
Theory $A_g^0 \sim 10^{-6}$ up to 10^{-4}
Never Measured



Very preliminar test on fitting the dalitz plot for $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$

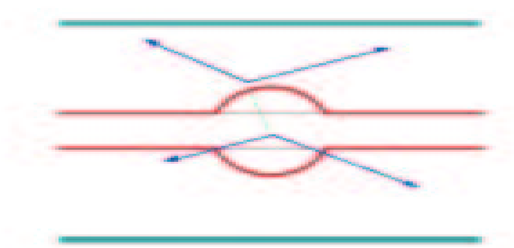
	KLOE 6.33 pb^{-1}	PDG
g	0.607±0.026	0.652±0.031
h	0.026±0.027	0.057±0.018
k	0.0080±0.0037	0.0197±0.0054

Measurement of K_L regeneration cross section

The incoherent regeneration cross section of K_L on Be and C is under measurement:

Carbon-fibers DC walls

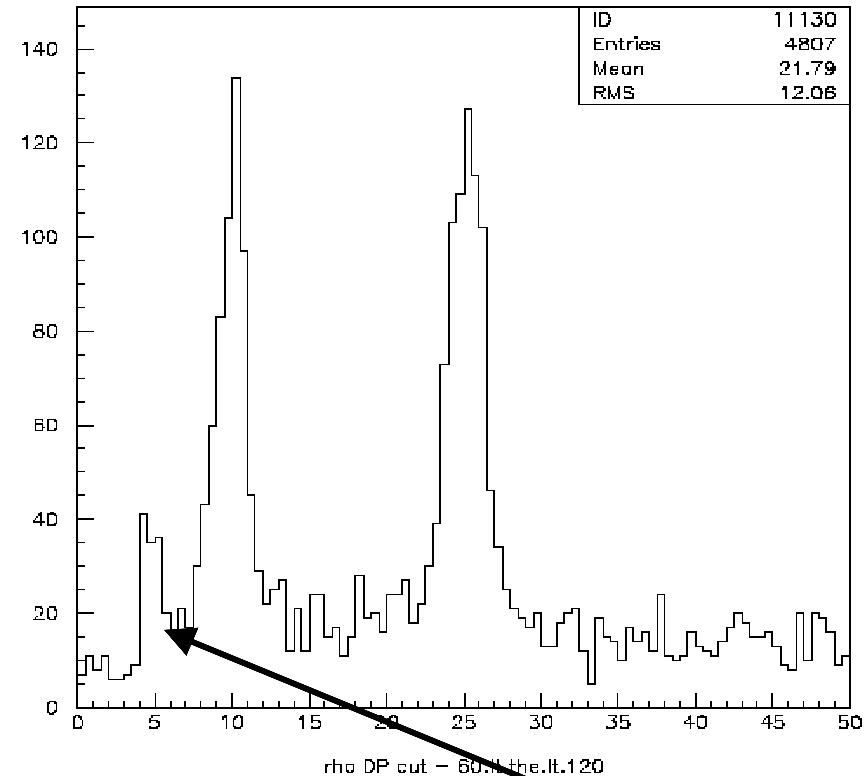
Be beam-pipe



- K_L tag via K_S decay into $\pi\pi$
- Secondary vtx in a cone around estimated K_L direction
- $M_{\pi\pi}$ close to M_{Kl}
- $\Delta P = |P_{Ks}| - |P_{Kl}|$ cut

  - Select CP + regeneration events
  - look at angular distributions

ρ(cm)



To separate the internal Be regenerator require secondary vertex to be with polar angles [60°,120°]

Conclusions and perspectives

✓ **DAFNE performance has improved considerably in the three years of data taking delivered luminosity is now ~ 3 pb^{-1} /day @ KLOE.**

Major interventions are scheduled for the next long winter shutdown:

1) FINUDA roll-in

2) Installation of a new interaction region in KLOE, with the goal of peak luminosity of $5\times10^{32}\ cm^{-2}\ s^{-1}$ CP/CPT starting from 2003/2004

Conclusions and perspectives

✓ **KLOE** detector is fully operational and reconstruction details well understood

→ From *2000 data* (25 pb^{-1}) results on K_S decay and ϕ radiative decay improving previous "PDG" knowledge

→ Analysis of 2001 data (190 pb^{-1}) in progress. New results on:

rare K_S and K_L decays and $K^{\pm}$ decays

η decays (6x10^6 η produced)

hadronic cross-section $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ $2m_\pi < W < m_\phi$

→ 2002 data taking is going on smoothly: 500 pb^{-1} expected by the end of the year