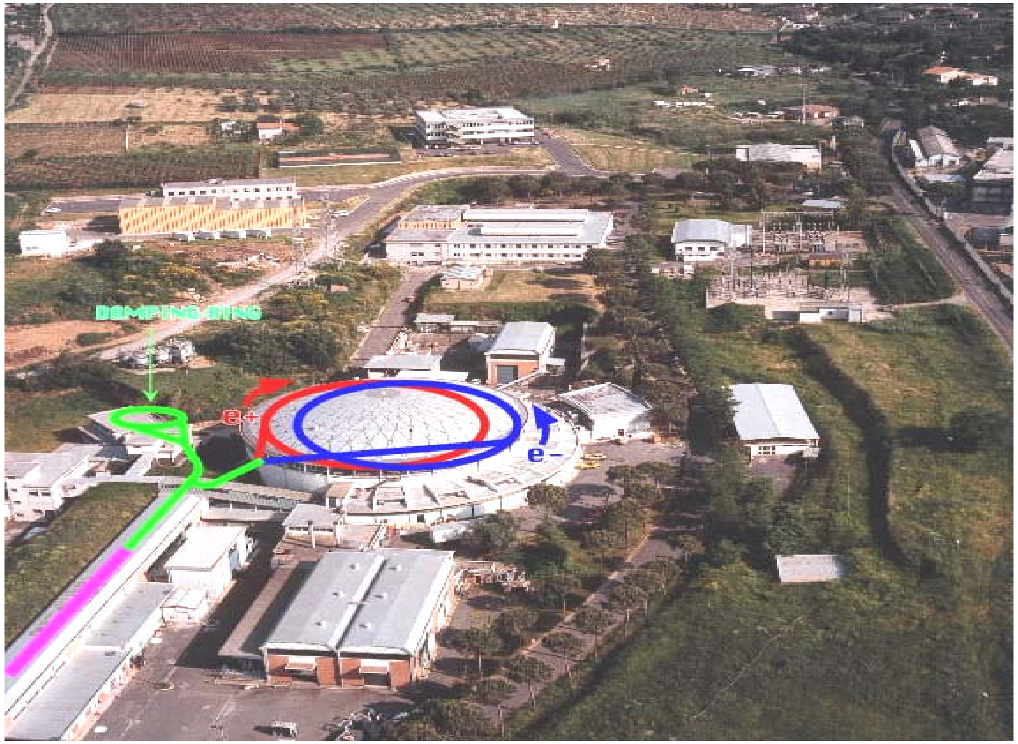
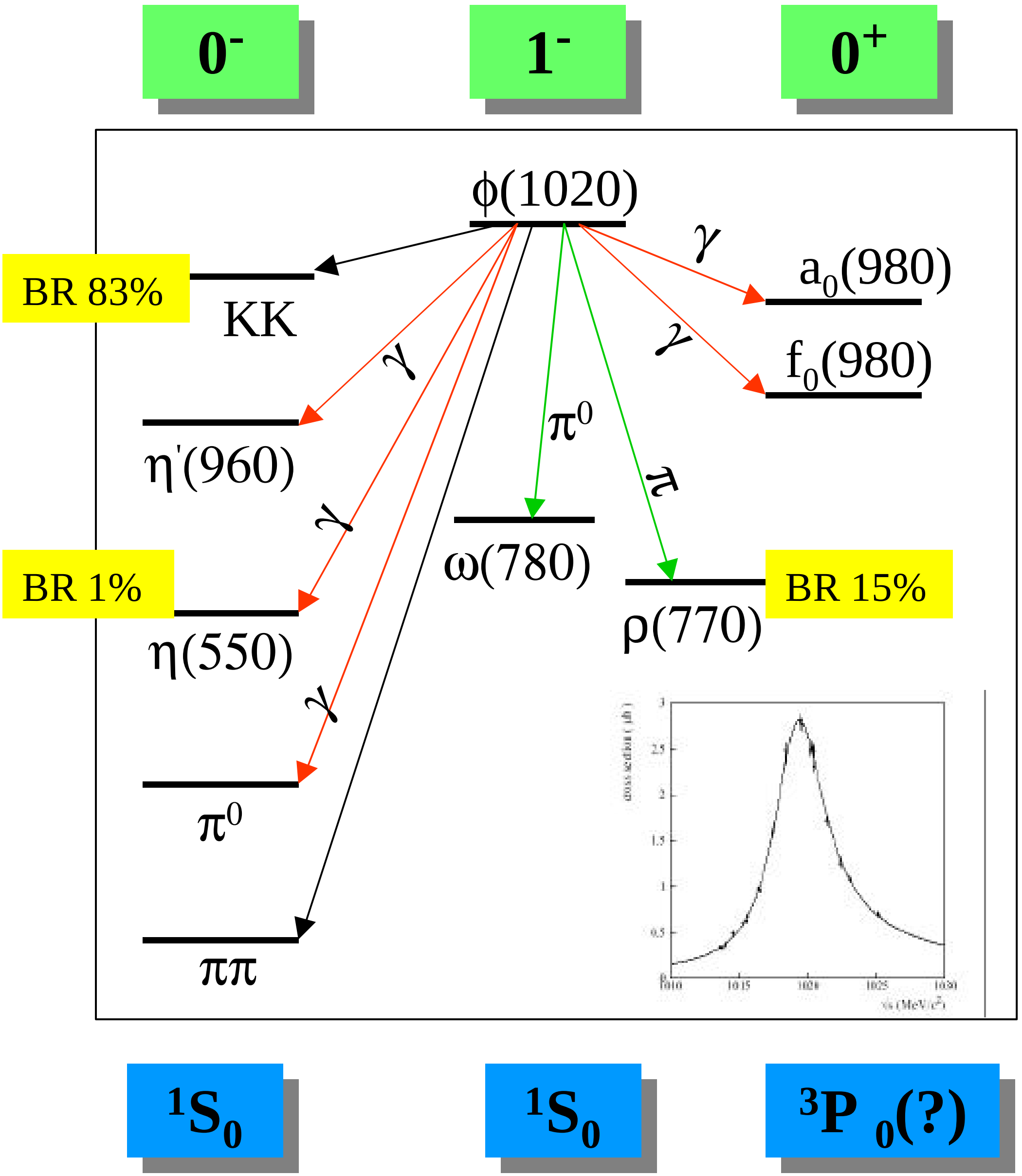
Recent results from KLOE



Luca Passalacqua
(LNF – INFN)
on behalf of the KLOE Collaboration

KLOE Physics Program



KAON physics

CP violation studies

- double ratio
- interference

CPT violation studies

- Semileptonic Asymmetries

$K_{S,L} \rightarrow \pi^+ e^- \nu \, / \, \pi^- e^+ \nu$

- interference

V_{us}, K form factors

$K_L \longrightarrow \pi^{\pm} \ell^{\mp} \nu, \quad K^{\pm} \longrightarrow \pi^o \ell^{\pm} \nu$

Rare $K_{S,L}$ decays

Non-KAON physics

Radiative ϕ decays

$\phi \longrightarrow f_o(980)\ \gamma,\ a_o(980)\ \gamma$

$\phi \longrightarrow \eta\ \gamma,\ \eta'\ \gamma$

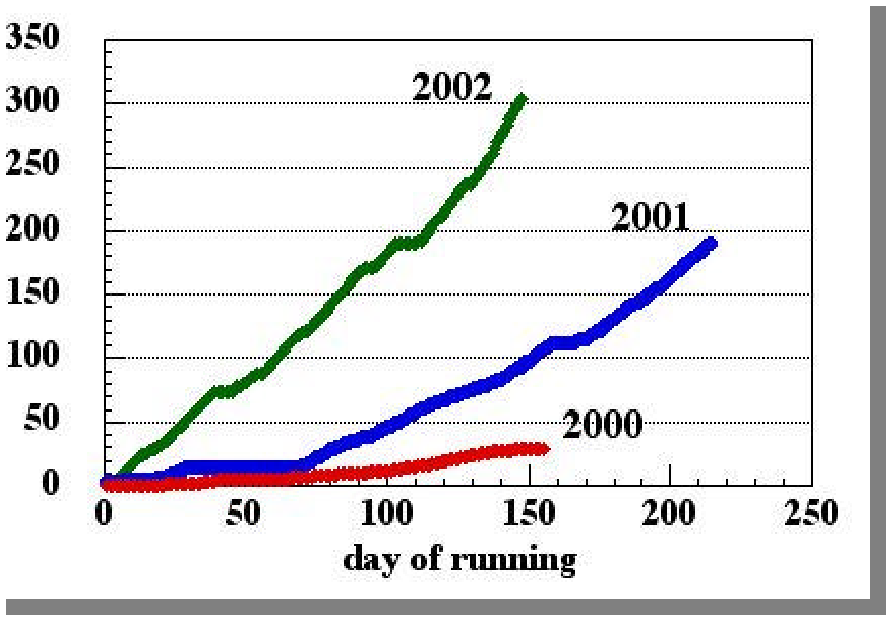
ϕ ® $\rho\,\pi,\ \pi^+\pi^-\pi^o$

Continuum physics

e+e- ® hadrons (*via* radiative return)

Summary of DAΦNE Operations

pb^{-1}



	Design	2002
◆ Max number of bunches	120	51
◆ Lifetime (min)	120	40
◆ Bunch current (mA)	40	20
◆ Single Bunch lum. (10^{30} $cm^{-2}s^{-1}$)	4.4	1.5
◆ Peak Luminosity (10^{32} $cm^{-2}s^{-1}$)	5.3	0.75
◆ φ per year (10^9)	15	0.9

March 1st 1998:
First collisions

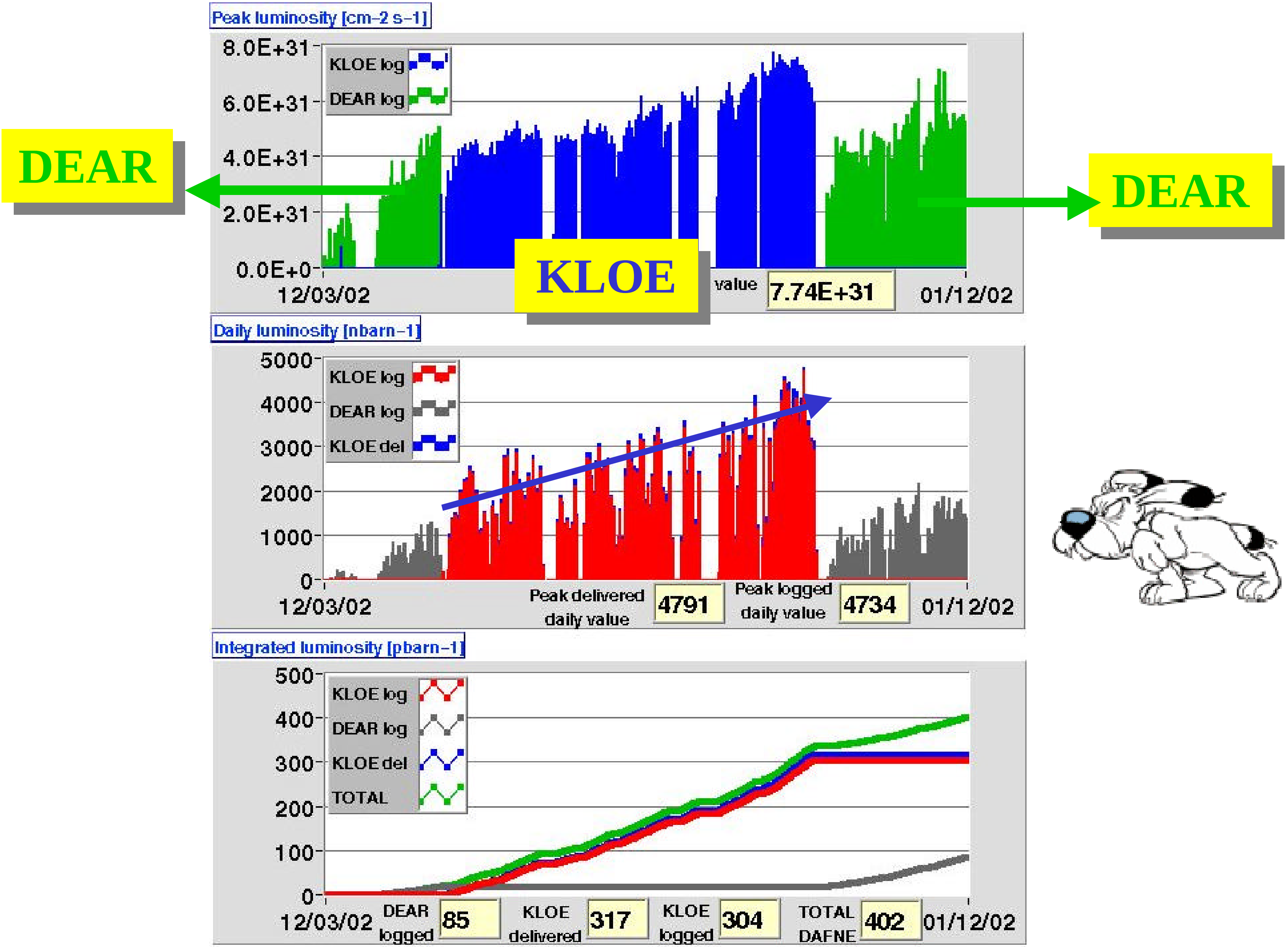
1999 run: 2.5 pb^{-1}
detector calibration

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

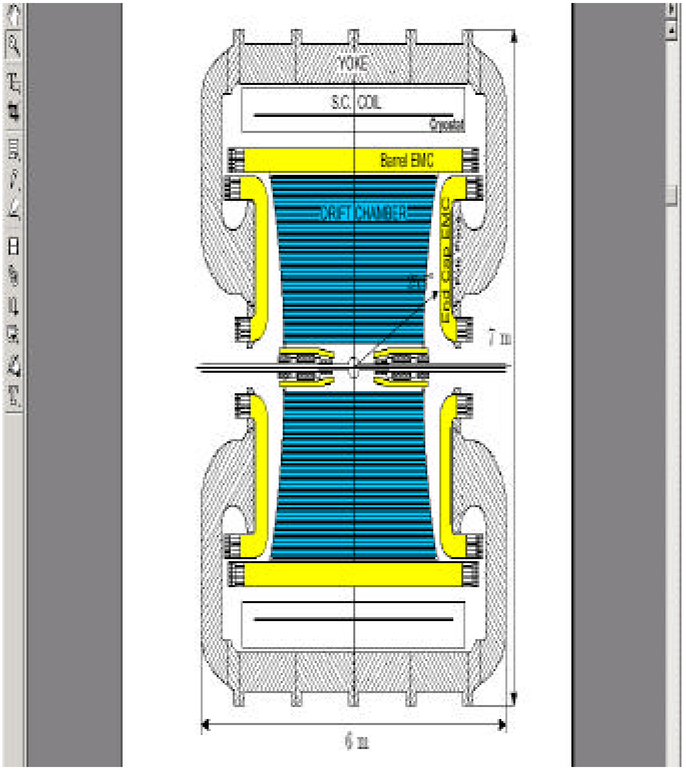
2001 run: 190 pb^{-1}
5.7 x 10^8 f
analysis in progress

2002 run: 300 pb^{-1}
9.0 x 10^8 f
analysis in progress

DAΦNE in 2002: still improving



The KLOE detector



Electromagnetic Calorimeter (EMC)

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

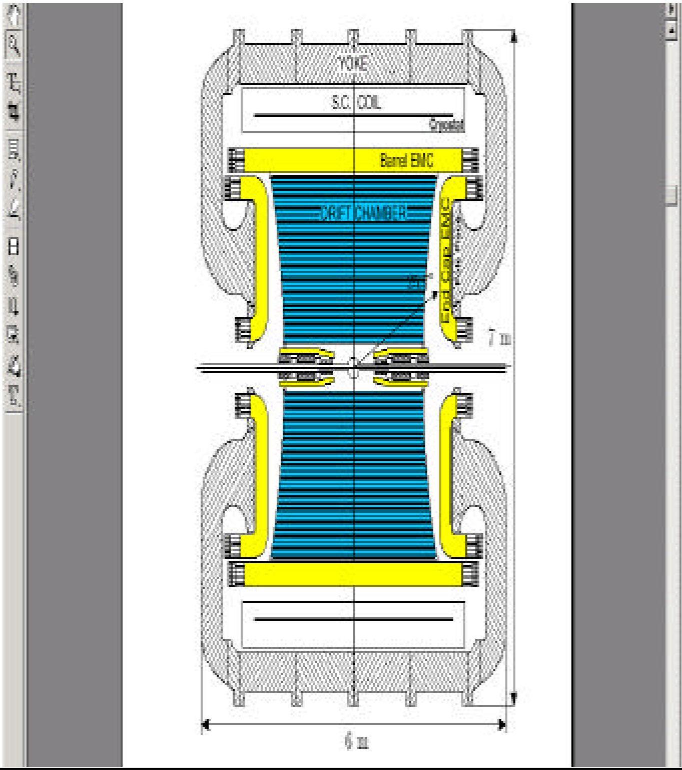
Drift Chamber (DC)

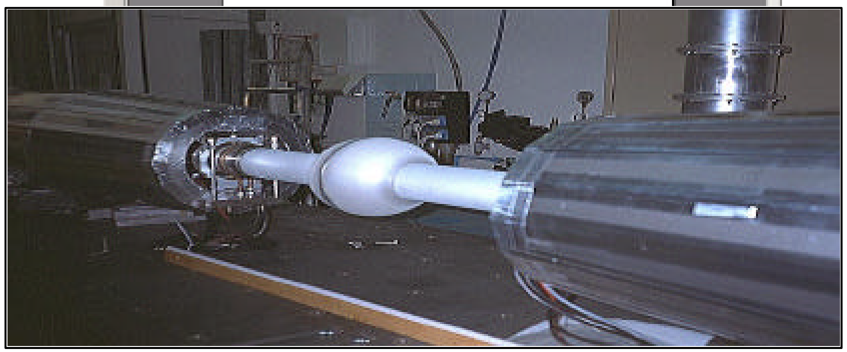
- Cylindrical structure, (4 m ∅×3.3 m)
- 12582/52140 sense/total wires
- All stereo geometry
- Helium (90 %) + Isobutan (10 %)

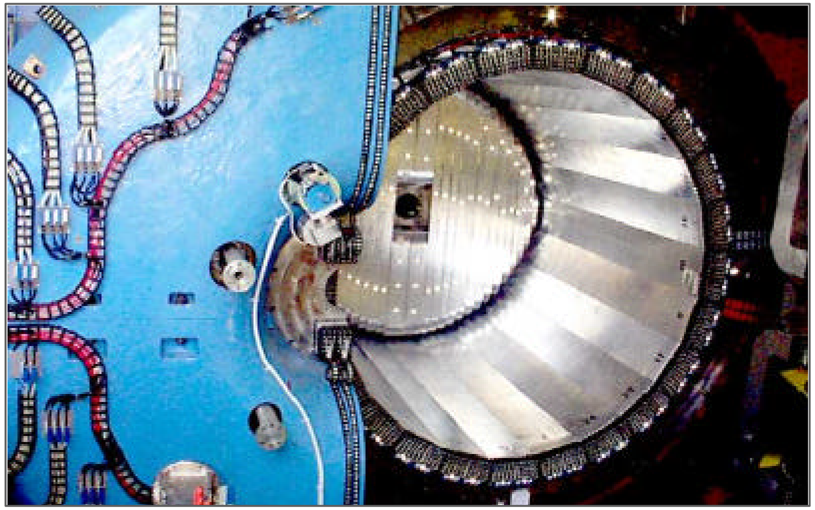
Quadrupole Calorimeter (QCAL)

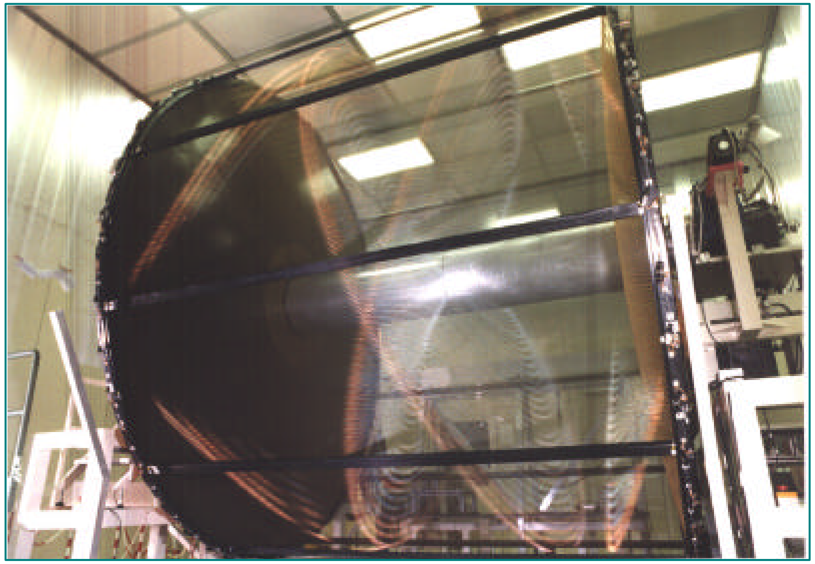
- Lead/Scintillator tile calorimeter inside KLOE

The KLOE detector



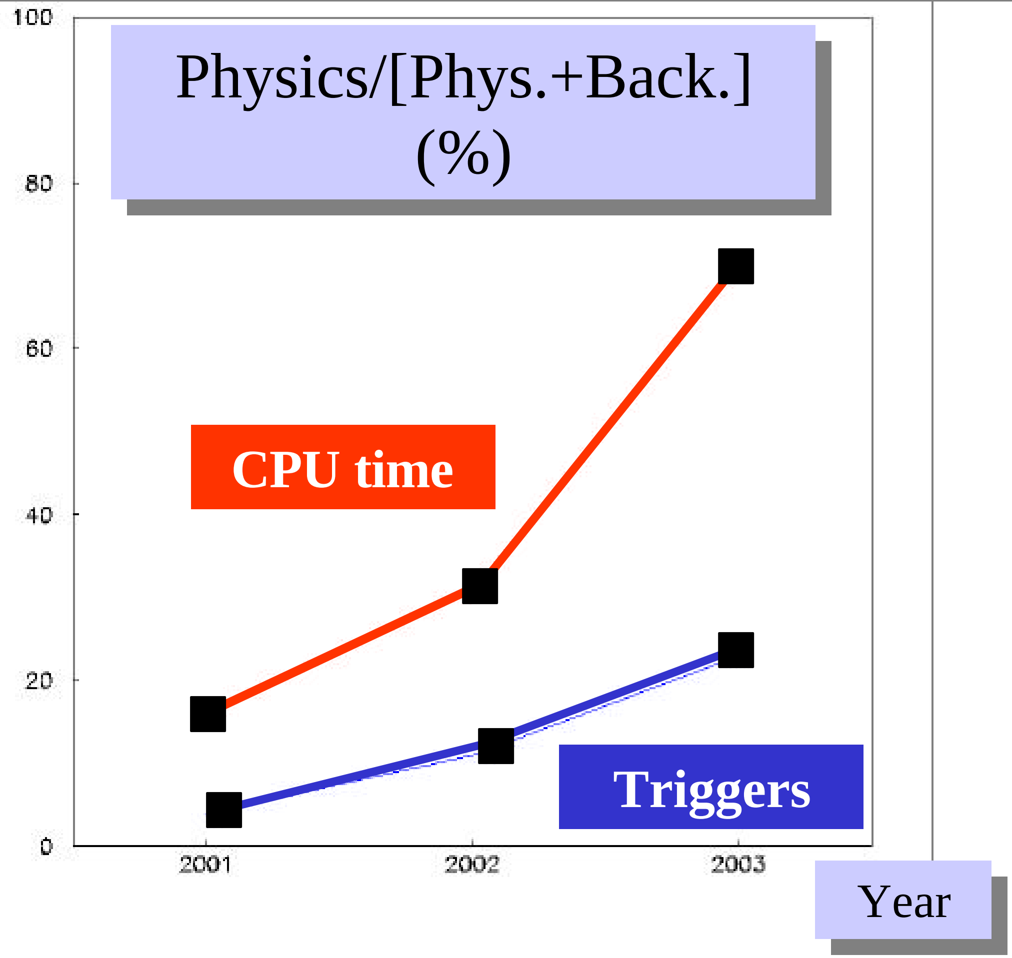






Detector related issues

- KLOE Detector performing according to design
- No aging so far
- Suffering intense, time varying, bkg from DAΦNE



year 2000
physics is a tiny fraction
computing was used for tracking background events

year 2001
DAΦNE gave more physics

year 2002
Physics is now 23 %
computing is now used for useful physics

KLOE Published Results: 2000 data

Kaon Physics

$G(K_S \rightarrow p^+p^-(g)) / G(K_S \rightarrow p^0p^0)$

$BR(K_S \rightarrow \pi^{\pm} e^{\mp} n)$

Non-Kaon Physics

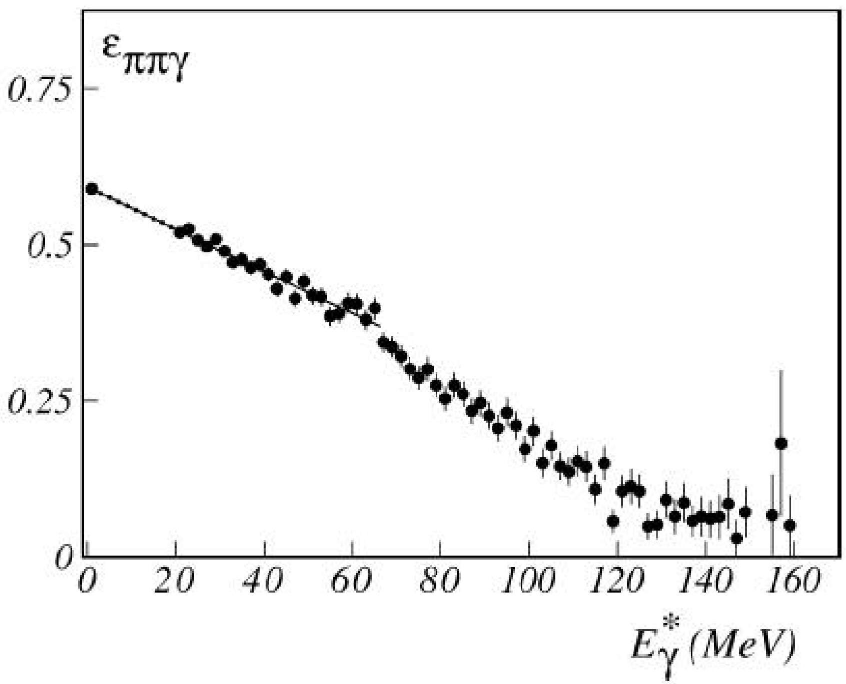
ϕ® hp^0g [$a_o(980)\ \gamma$]

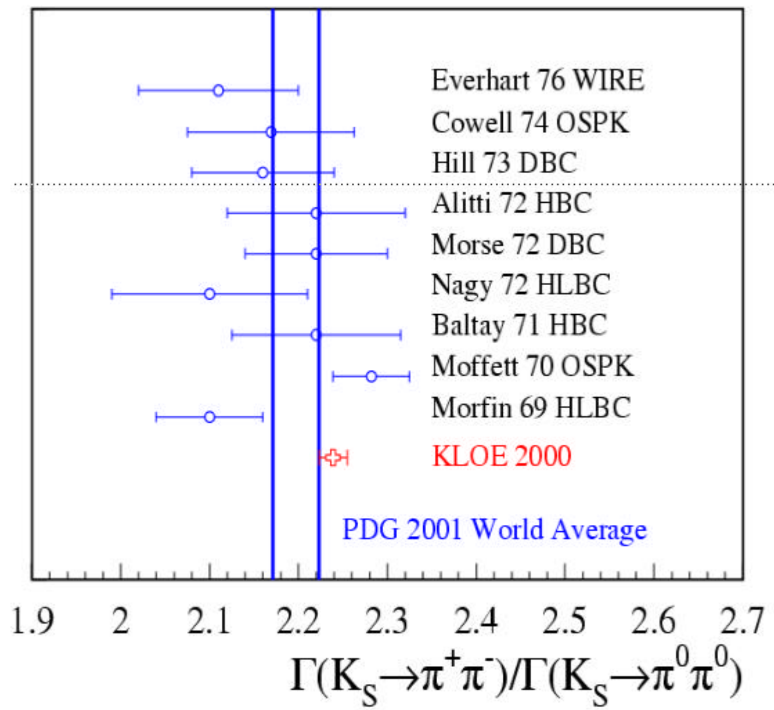
ϕ® p^0p^0g [$f_o(980)\ \gamma$]

ϕ® h'g / ϕ® hg [**h'-h** mixing]

Kaon Physics

$K_s \rightarrow p^+p^-(g) / K_s \rightarrow p^0\, p^0$





KLOE 2000 data **2.239 ± 0.003(stat) ± 0.015(sys)**
PDG 2002 **2.197 ± 0.026**

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- Measurement done on Y2K 17 pb^{-1}

N($Ks \rightarrow \pi^+\pi^-$) = 1.098×10^6

N($Ks \rightarrow \pi^0\pi^0$) = 0.788×10^6

Isospin decomposition

$$\frac{BR(K_S \rightarrow \boldsymbol{p}^{\pm}\boldsymbol{p}^{\pm})}{BR(K_S \rightarrow \boldsymbol{p}^{0}\boldsymbol{p}^{0})} \cong \sqrt{\frac{m_K^2 - 4m_{p^{\pm}}^2}{m_K^2 - 4m_{p^0}^2}} \left[2 + 6\sqrt{2}\,\frac{A_2}{A_0}\cos\left(\boldsymbol{d}_2 - \boldsymbol{d}_0\right) \right]$$

Neglecting ΔI=5/2 EM contributions:

$$\left(A_0 / A_2\right)^2 \cong \frac{3}{4}\frac{\boldsymbol{t}_S}{\boldsymbol{t}_+}\frac{1}{BR(K^{\pm} \rightarrow \boldsymbol{p}^{\pm}\boldsymbol{p}^{0})} - 1 = \left(22.2 \pm 0.07\right)^2$$

Using PDG values for the $K^0 \rightarrow \pi^+\pi^-/\pi^0\pi^0$ BRs:

$$\delta_0 - \delta_2 \cong (56.7 \pm 3.8)^{\circ}$$

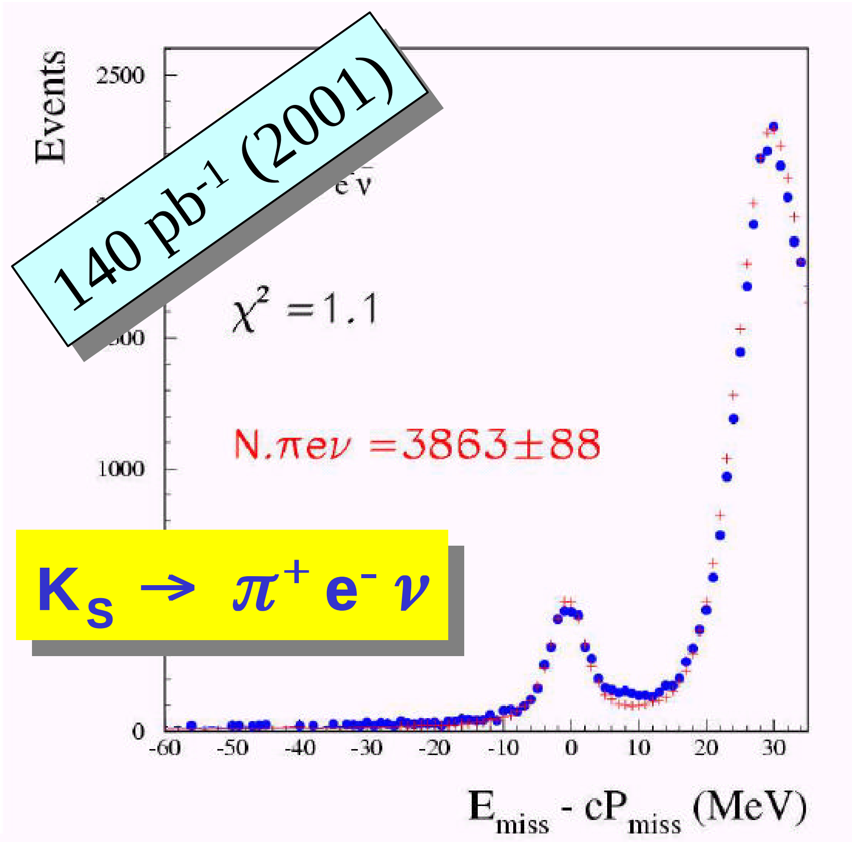
This value is in disagreement with:

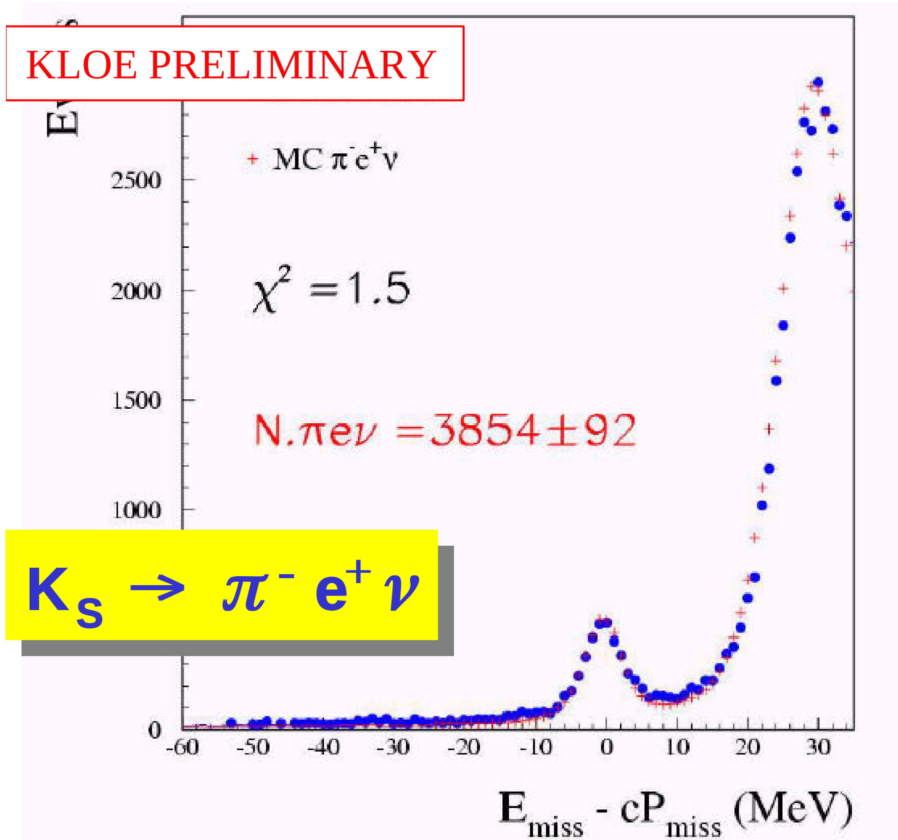
- the prediction from $O(p^2)$ χpT [Gasser *et al.* '91] $\delta_0 - \delta_2 \cong (45 \pm 6)^{\circ}$
- the value from $\pi\pi$ scattering [Gasser *et al.* '01] $\delta_0 - \delta_2 \cong (45.2 \pm 1.3 \pm {}^{4.5}_{1.6})^{\circ}$

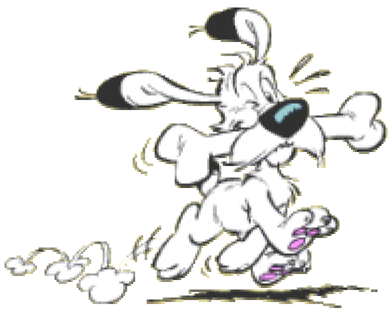
While with the KLOE measurement

$$\delta_0 - \delta_2 \cong (48 \pm 3)^{\circ}$$

$K_S \rightarrow \pi^+ e^- \nu \,/\, \pi^- e^+ \nu$







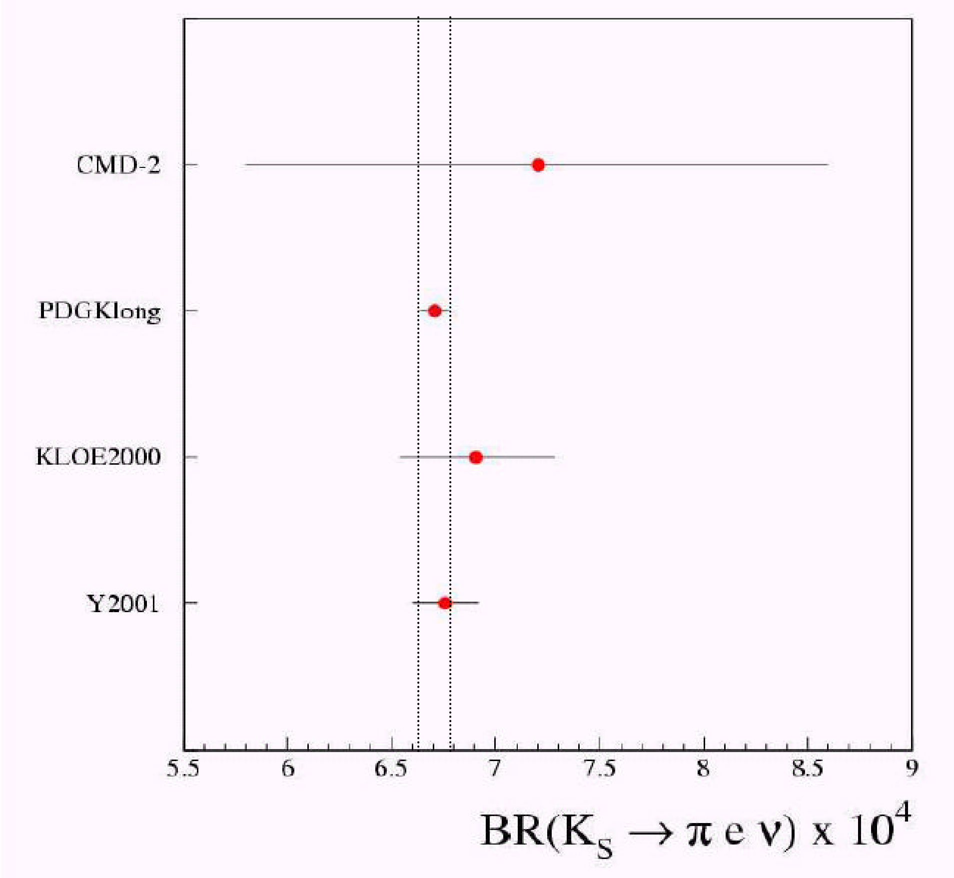
$$\mathbf{BR}(\pi^- e^+ \nu) = (3.44 \pm 0.09_{\,stat} \pm 0.06_{\,syst})\ 10^{-4}$$

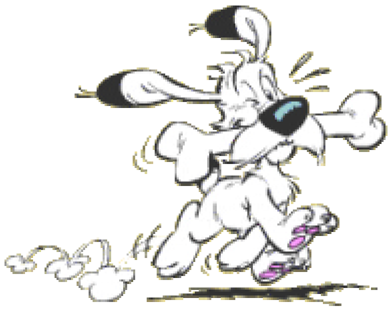
$$\mathbf{BR}(\pi^- e^+ \nu) = (3.31 \pm 0.08_{\,stat} \pm 0.05_{\,syst})\ 10^{-4}$$

$$\mathbf{BR}(\pi^\pm e^\mp n) = (6.76 \pm 0.12_{\,stat} \pm 0.10_{\,syst})\ 10^{-4}$$

KLOE PRELIMINARY

$K_S \rightarrow \pi^+ e^- \nu$ / $\pi^- e^+ \nu$





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$BR(\pi^\pm e^\mp n) = (6.76 \pm 0.12_{stat} \pm 0.10_{syst})\ 10^{-4}$

KLOE PRELIMINARY

Leptonic Asymmetries

$$\langle e^+\pi^-\nu \,|\, H_{WK} \,|\, K^0\rangle = a + b$$
$$\langle e^-\pi^+\bar{\nu} \,|\, H_{WK} \,|\, \bar{K}^0\rangle = a^* - b^*$$

$$\langle e^-\pi^+\bar{\nu} \,|\, H_{WK} \,|\, K^0\rangle = c + d$$
$$\langle e^+\pi^-\nu \,|\, H_{WK} \,|\, \bar{K}^0\rangle = c^* - d^*$$

T	$Im\, a = Im\, b = Im\, c = Im\, d = 0$
CP	$Im\, a = Re\, b = Im\, c = Re\, d = 0$
CPT	$b = d = 0$
$\Delta S=\Delta Q$	$c = d = 0$

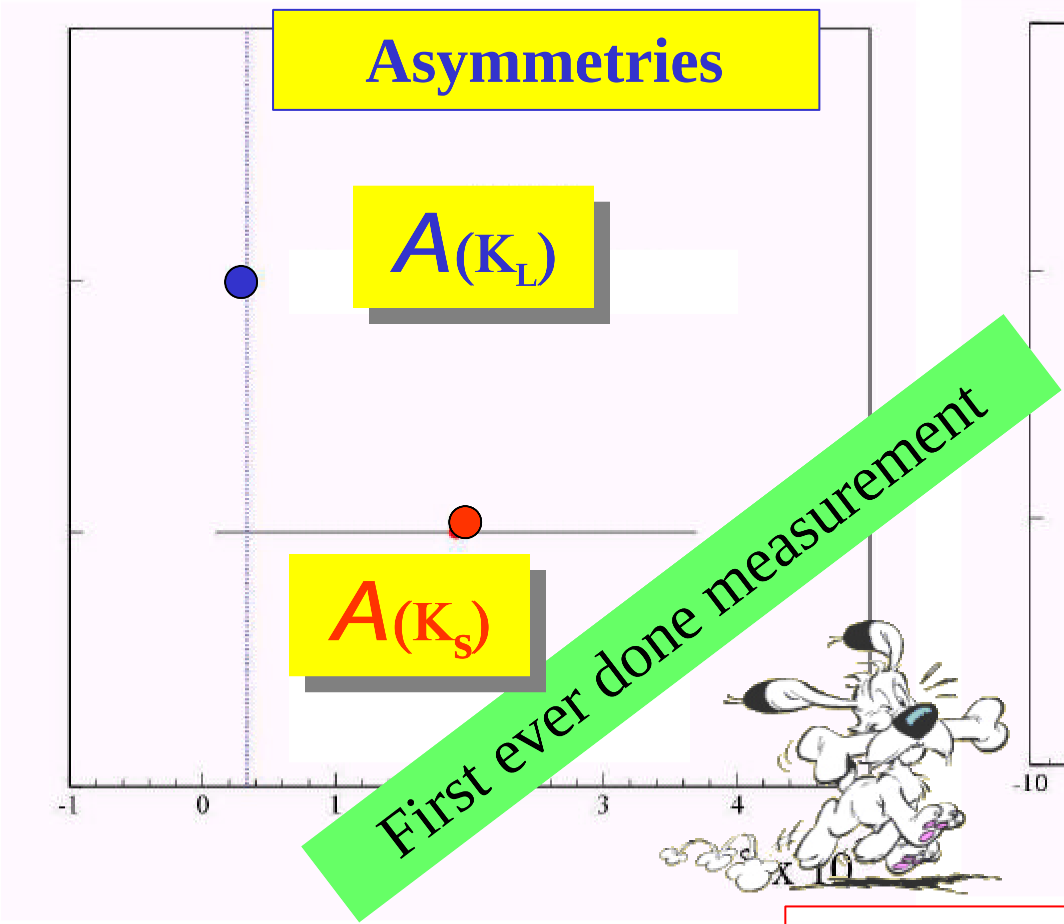
$$A_{S,L} = \frac{\Gamma^+_{S,L} - \Gamma^-_{S,L}}{\Gamma^+_{S,L} + \Gamma^-_{S,L}} \quad \begin{cases} A_S = 2\Re(\varepsilon_K)+2\Re(\delta_K)+2\Re(b/a)-2\Re(d^*/a) \\ A_L = 2\Re(\varepsilon_K)-2\Re(\delta_K)+2\Re(b/a)+2\Re(d^*/a\,) \end{cases}$$

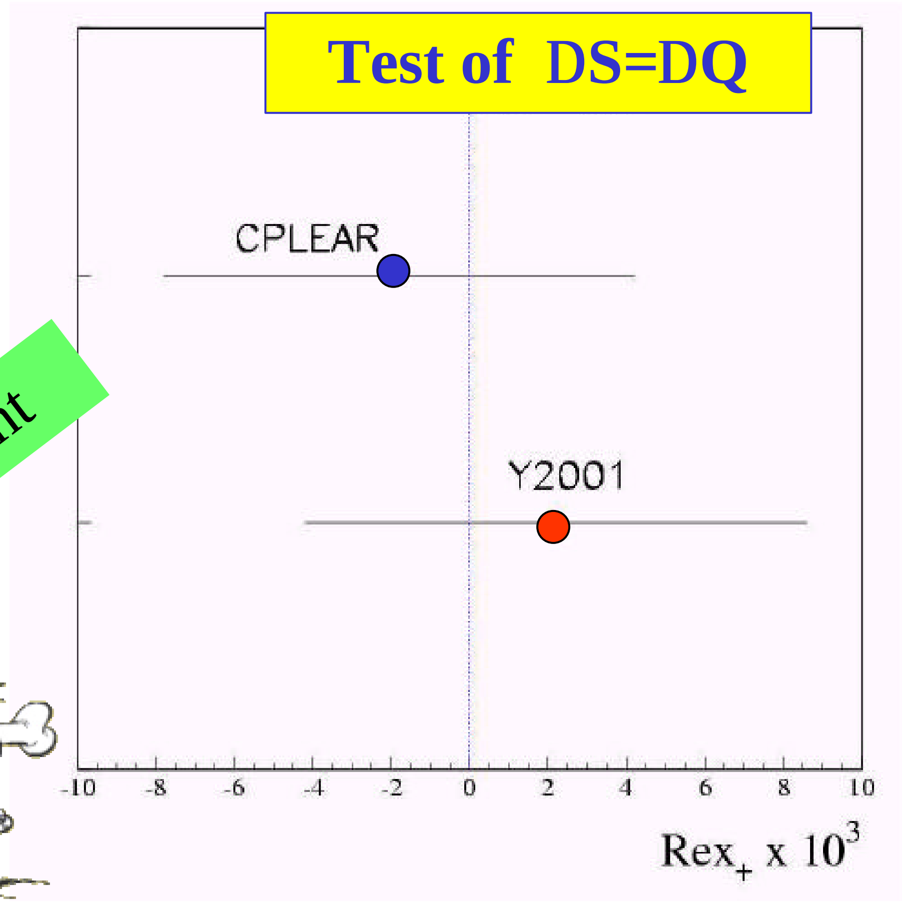
~~CP~~ | ~~CPT~~ in mixing | ~~CPT~~ in decay | $\Delta S\neq\Delta Q$ and ~~CPT~~

$A_S - A_L \neq 0$ implies ~~CPT~~

$$\frac{\Gamma_S^{semi}}{\Gamma_L^{semi}} = 1+4\Re(x_+) \approx 1+4\Re(c^*/a)$$

Comparison with KTeV/CPLEAR





KLOE PRELIMINARY

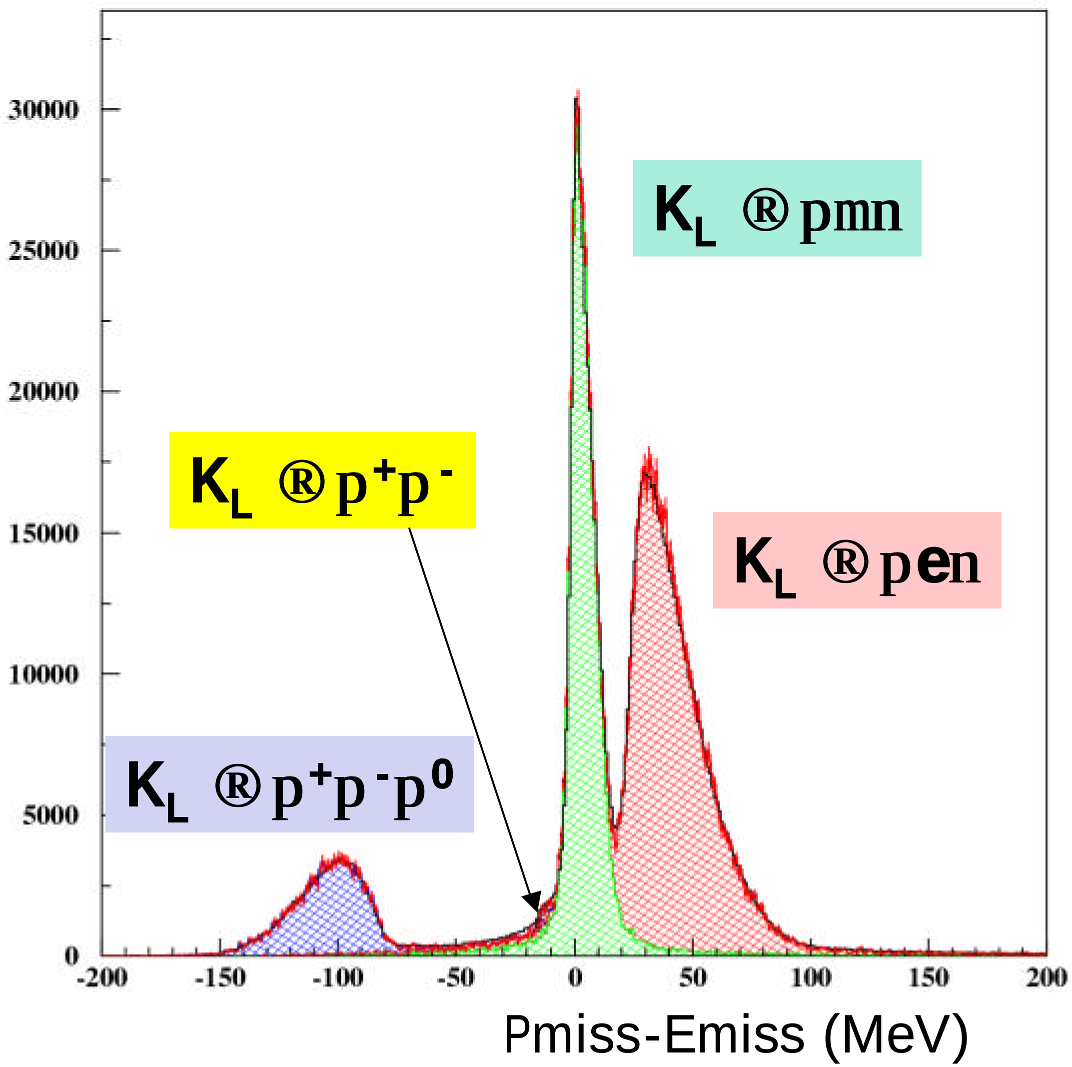
kTEV $A(K_L)=(3332\pm58\pm47)\,10^{-6}$

KLOE $A(K_S)=(1.9\pm1.7\pm0.6)\,10^{-2}$

CPLEAR $\Re(x_+)=(-1.8\pm4.1\pm4.5)10^{-3}$

KLOE $\Re(x_+)=(+2.2\pm5.3\pm3.5)10^{-3}$

$K_L \rightarrow$charged



KLOE(2002)

$K\mu3=0.384\pm0.002$(stat)

$Ke3=0.271\pm0.002$(stat)

$K\pi3=0.132\pm0.002$(stat)

$K\pi\pi=$ **$(2.04\pm0.04)10^{-3}$**

PDG

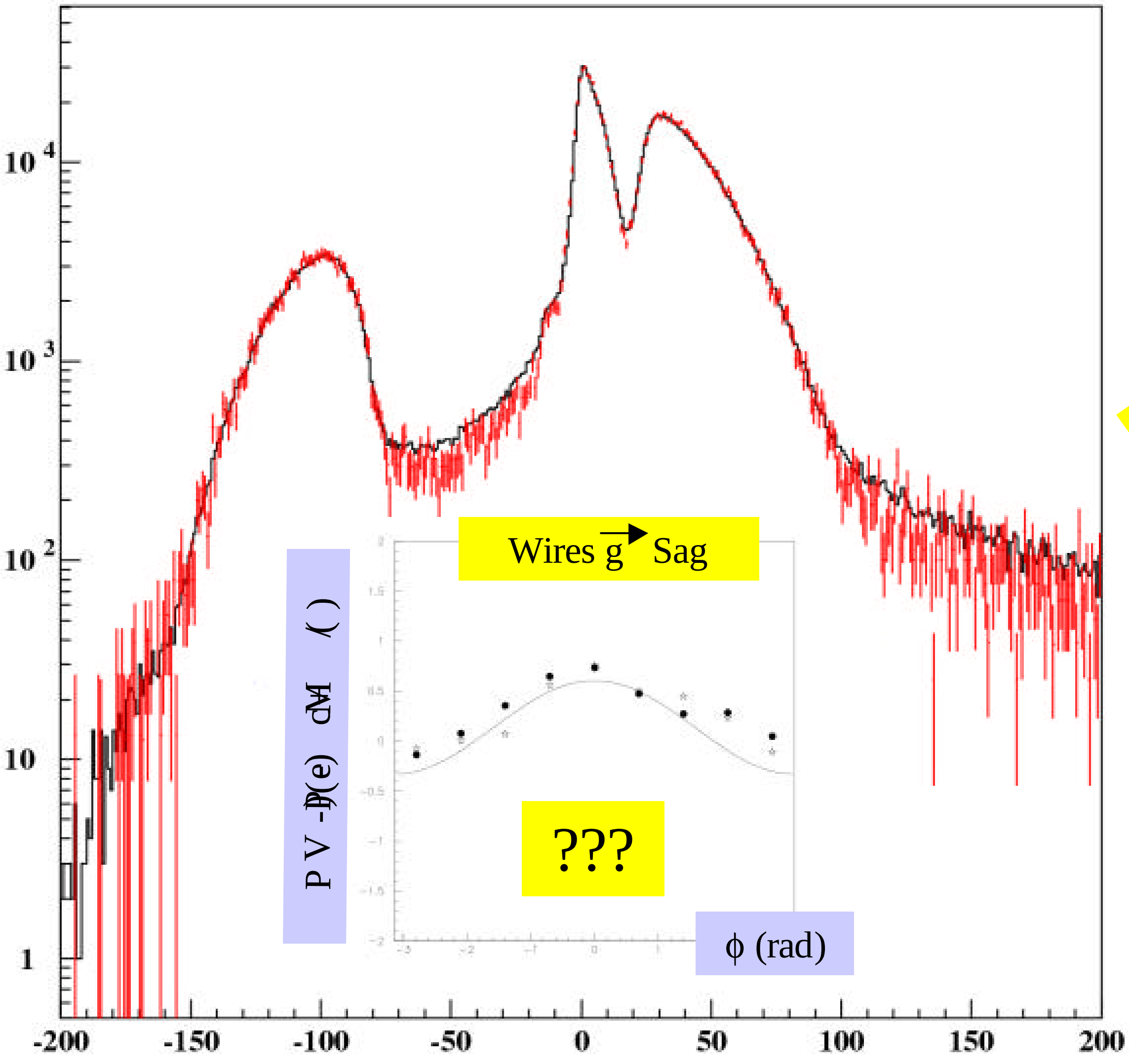
$K\mu3=0.388\pm0.003$

$Ke3=0.272\pm0.002$

$K\pi3=0.126\pm0.002$

$K\pi\pi=$ **$(2.08\pm0.03)10^{-3}$**

$K_L \rightarrow$ charged



KLOE(2002)

Kμ3=0.384±0.002 … t)

Ke3=0.271±0. … (stat)

Kπ3=0.13 … 02(stat)

Kππ= … 4±0.04)10^{-3}

NOT TO BE QUOTED

PDG

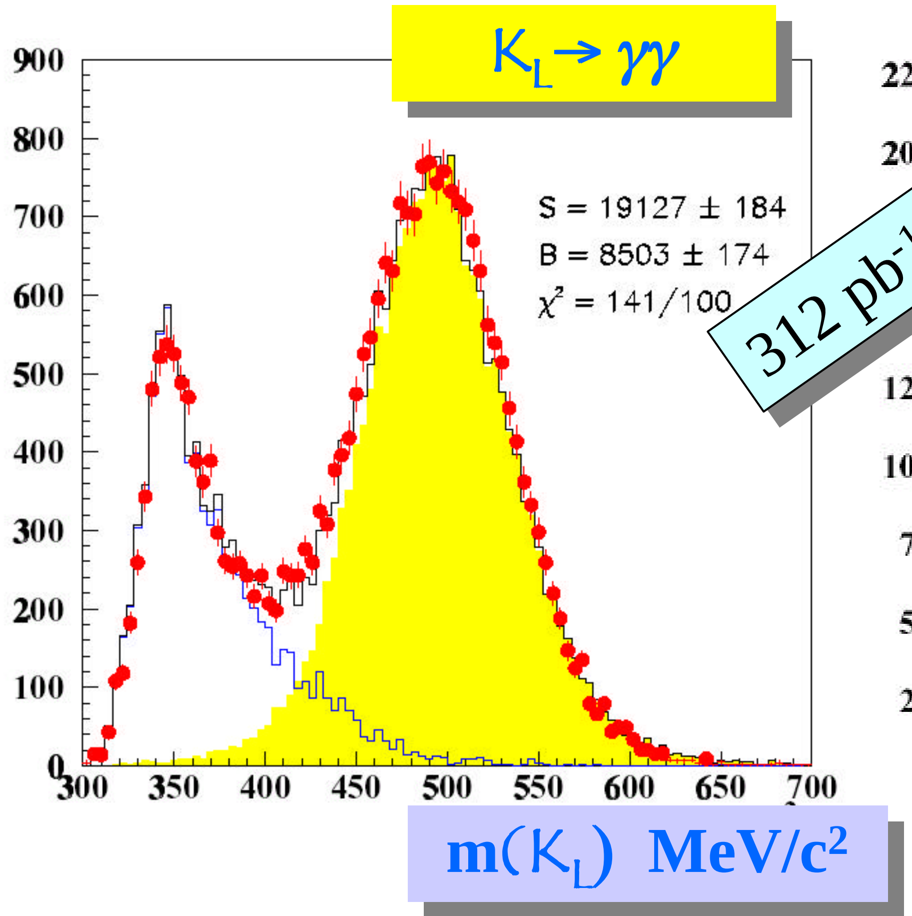
Kμ3=0.388±0.003

Ke3=0.272±0.002

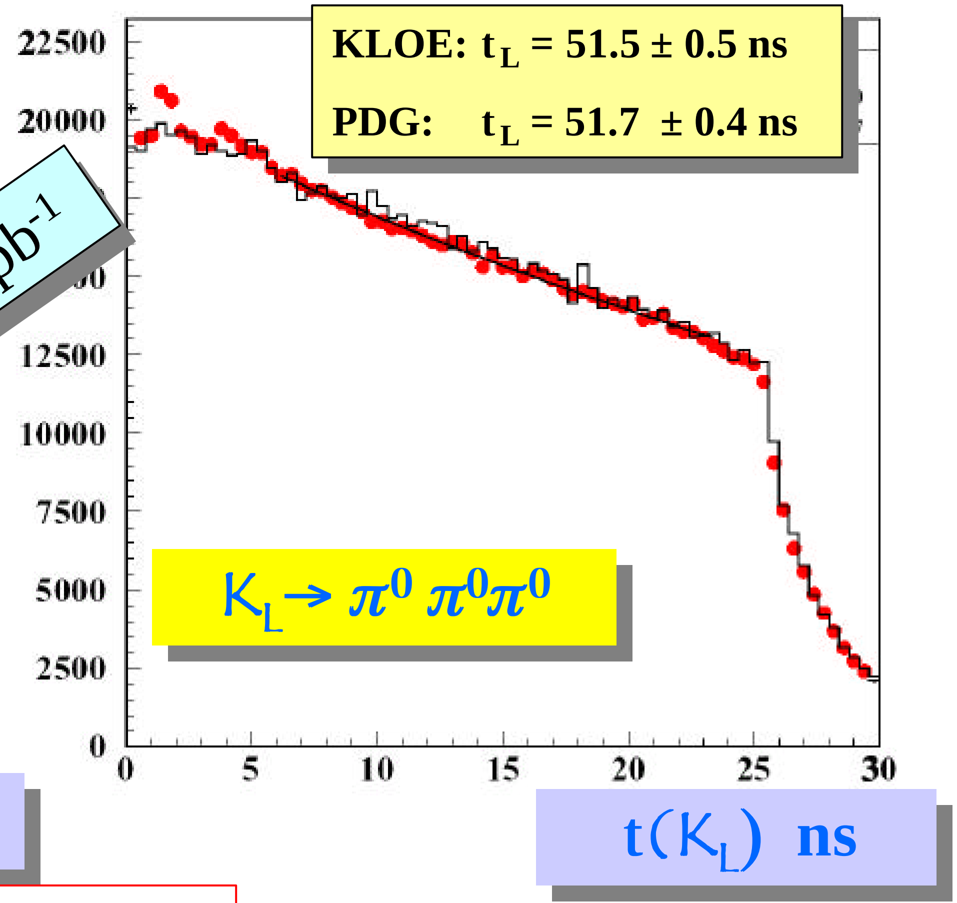
Kπ3=0.126±0.002

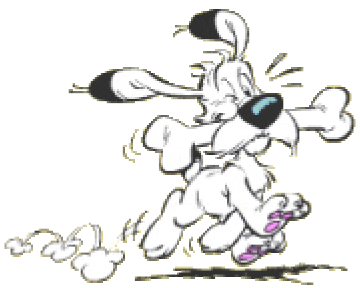
Kππ= **(2.08±0.03)10^{-3}**

$K_L \to gg$ / $K_L \to p^0\ p^0 p^0$



312 pb^{-1}

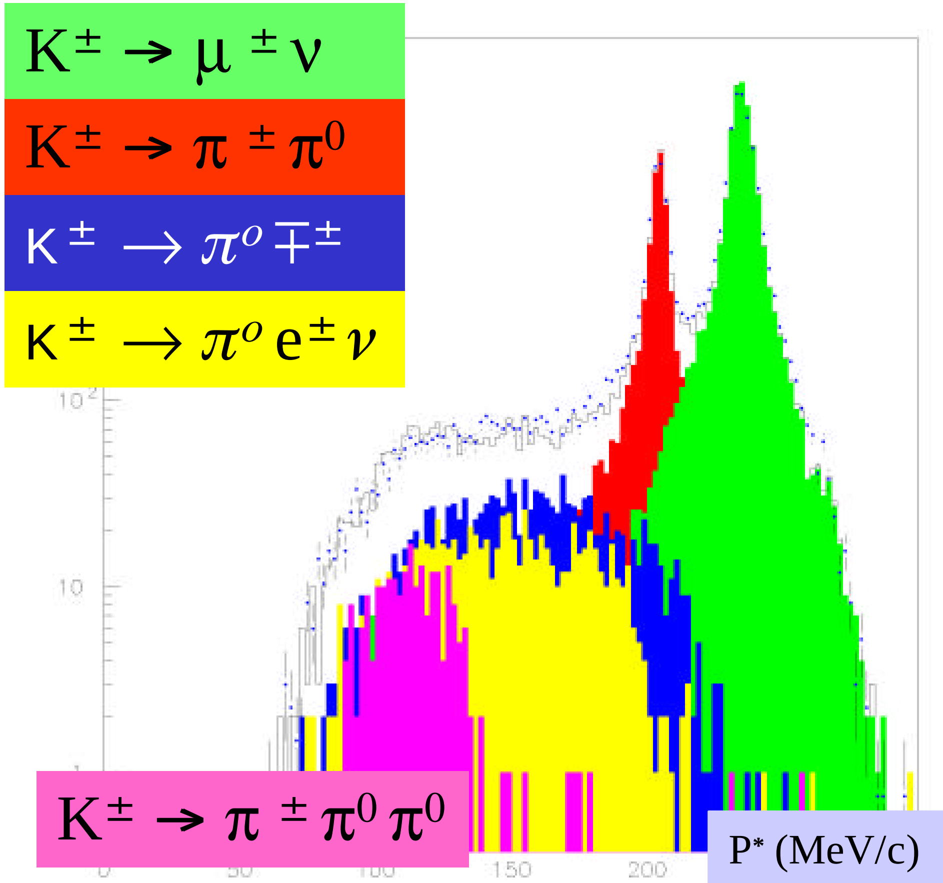




KLOE Note 182

KLOE 2002	$(2.80 \pm 0.03_{stat} \pm 0.02_{syst})$	10^{-3}
NA48 2002	$(2.81 \pm 0.01_{stat} \pm 0.02_{syst})$	10^{-3}
PDG 2002	**(2.82 ± 0.08)**	10^{-3}

Charged Kaons

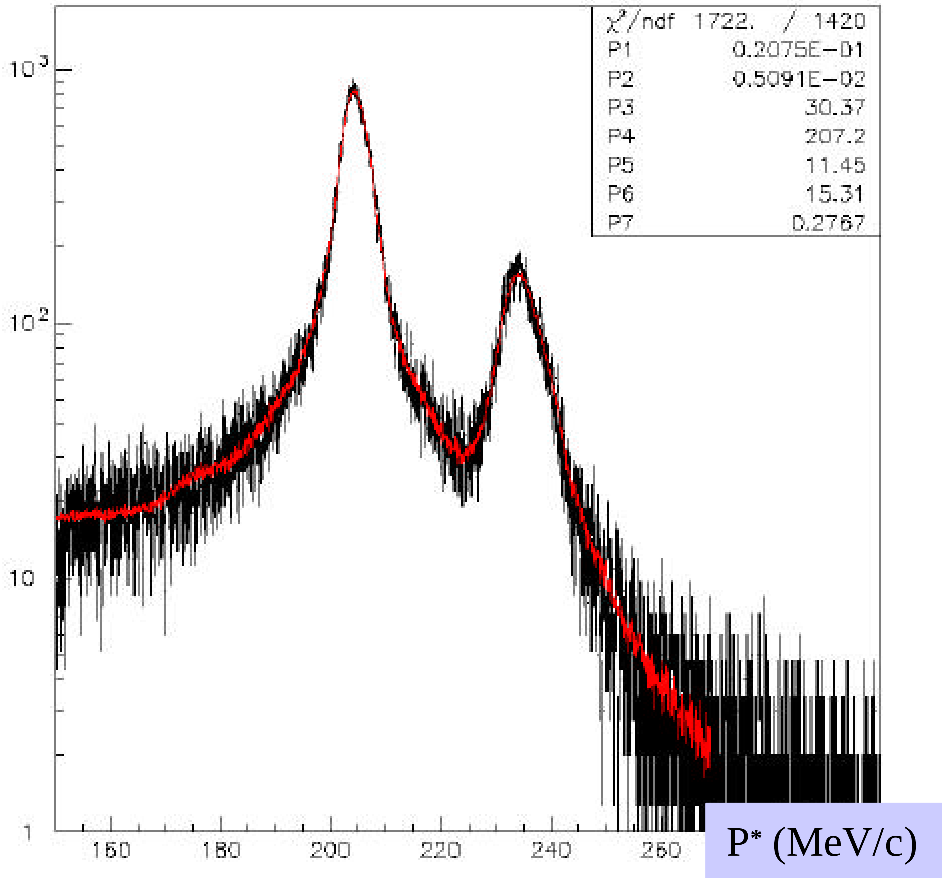


Harvest of measurements, including V_{us}, waiting for on-going *ad hoc* reprocessing with:

•improved tracking at low β;

•better rejection of vicious machine background.

Charged Kaons



Harvest of measurements, including V_{us}, waiting for on-going *ad hoc* reprocessing with:

•improved tracking at low β;

•better rejection of vicious machine background.

$$\frac{\Delta|V_{us}|}{|V_{us}|} = 0.5\left(\frac{\Delta BR_{K_{e3}}}{BR_{K_{e3}}} + \frac{\Delta t}{t}\right) + 0.05\frac{\Delta I_+}{I_+} + \frac{\Delta f_+(0)}{f_+(0)}$$

BRs essentially from[Chiang *et al.*, '72].,

$K^{\pm}_{e3}$ 0. 59% 0.22% 0. 86%

Prospects for ε'/ε

$$doubleRatio = \frac{BR(K_L \to \pi^+\pi^-)/BR(K_S \to \pi^+\pi^-)}{BR(K_L \to \pi^0\pi^0)/BR(K_S \to \pi^0\pi^0)} = 1 + 6 \times \mathrm{Re}\left(\frac{\varepsilon'}{\varepsilon}\right)$$

K_L

Statistical error : » 1%

Contributions to the systematic error :

Presently at about 2% level, improving by work on:

- **Residual effects in tracking (gravitational sags)**
- **Separation of overlapping clusters**
- **Regeneration**

Need at least x10 data to reach the 10^{-4} *régime*

K_S

Statistical error : already negligible

Contributions to the systematic error

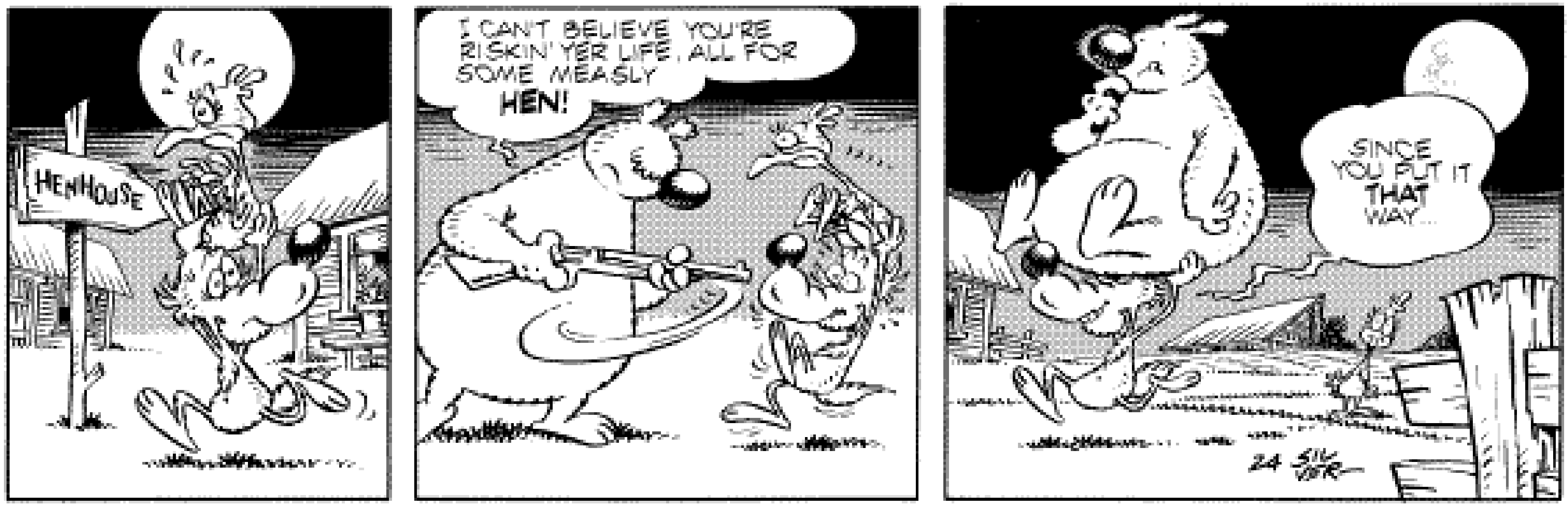
Source	Error, %
Tagging	0.55
γ-counting	0.20
trigger and t_0	0.23
tracking	0.26

Now ~0.1%

Total error 0.68 %

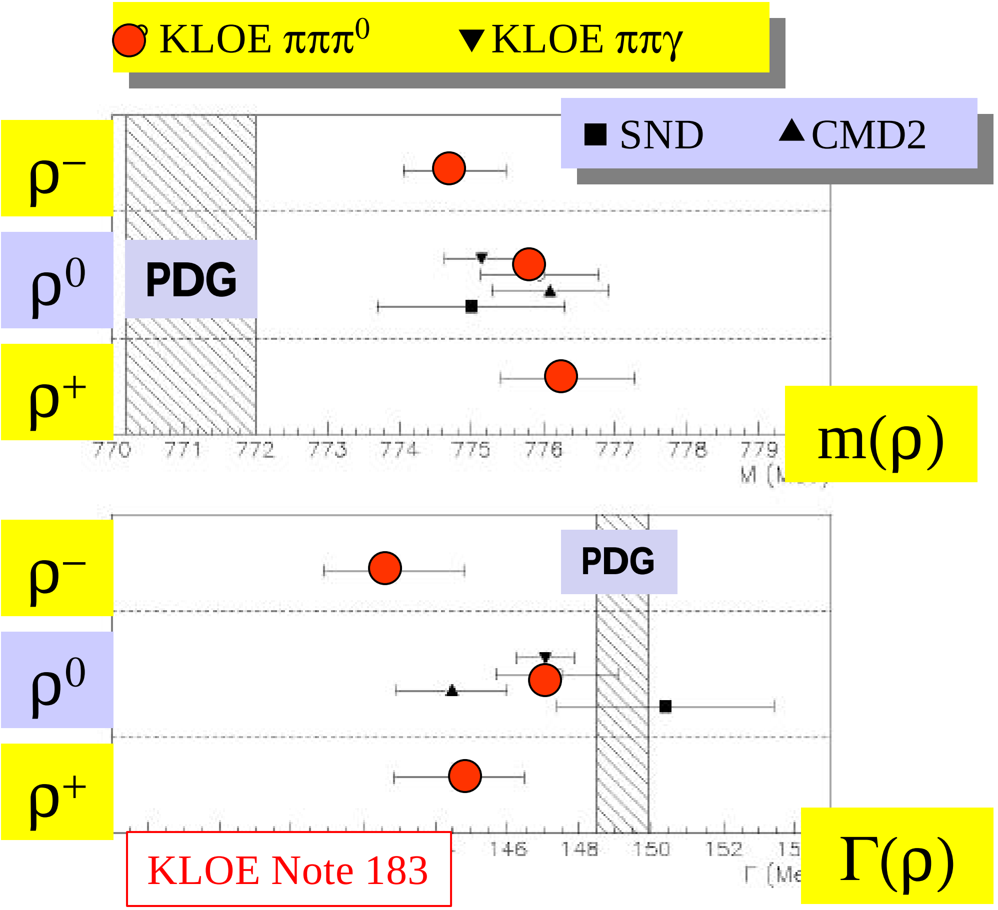
Should scale down to 0.1% on full data set

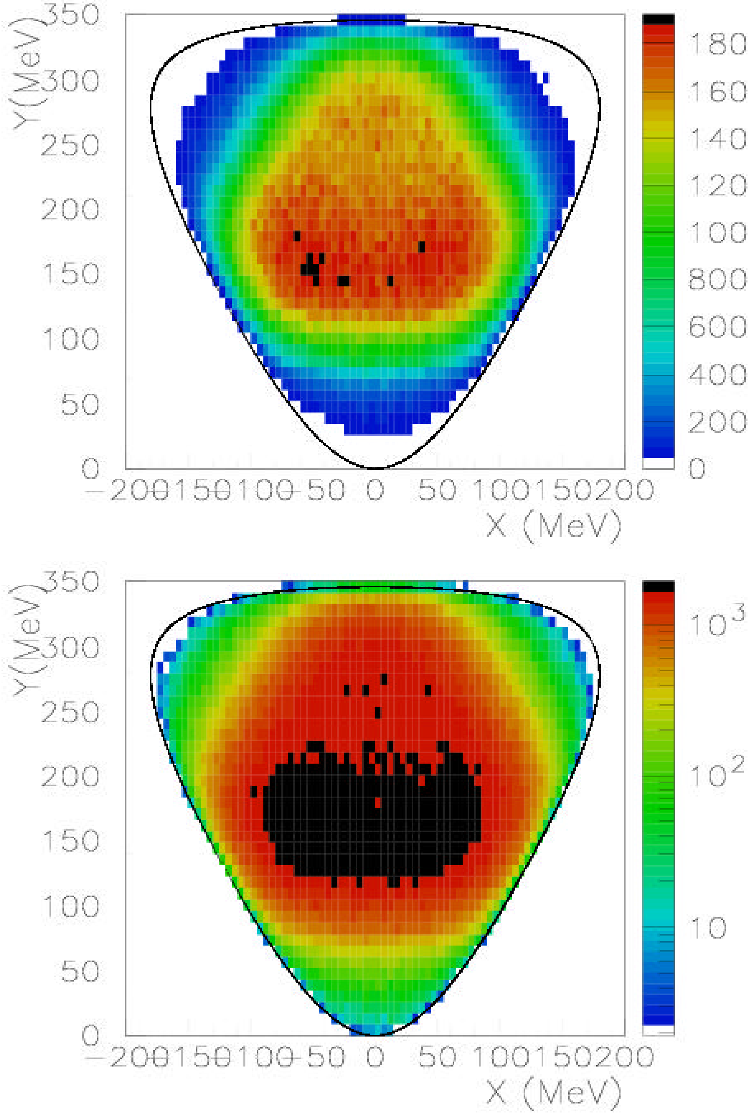
Non-Kaon Physics



$\phi \to (\rho\pi) \to \pi^+\pi^-\pi^0$

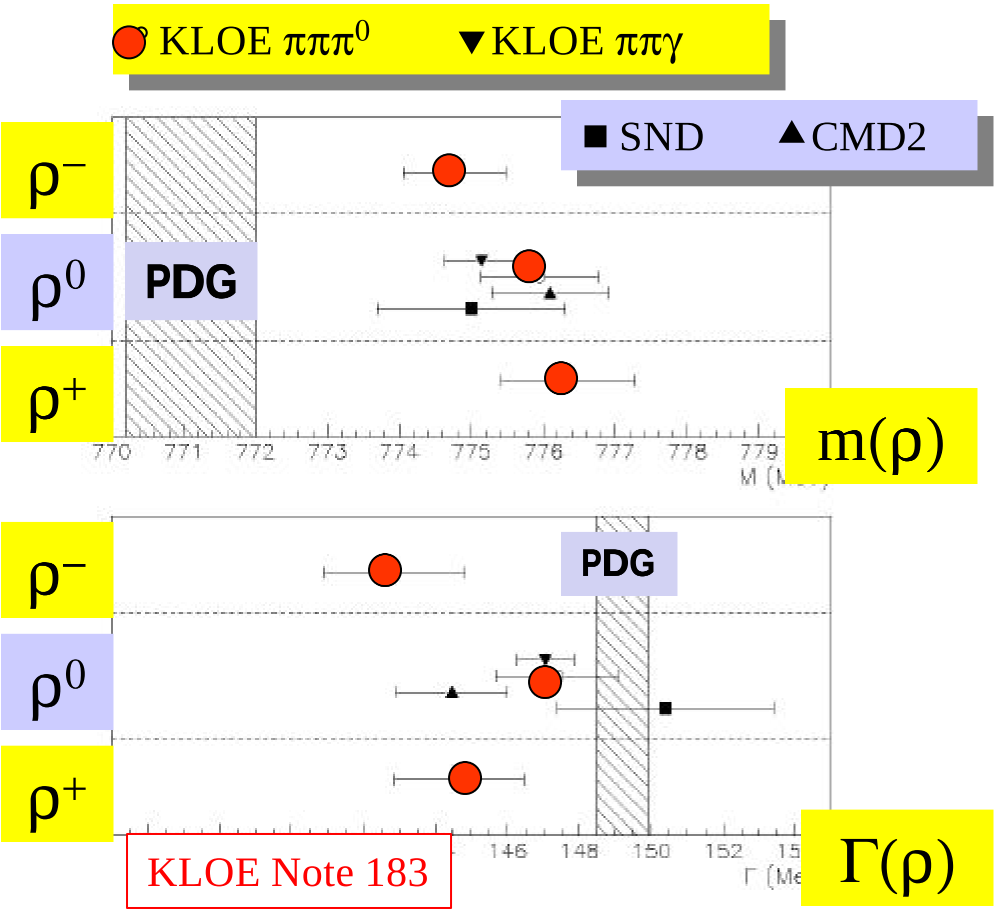
Y2K 17 pb^{-1} analysis of Dalitz Plot allowed to extract ρ parameters (m,Γ) for each state of charge and non-ρ contributions (direct, $\omega\pi^0$, ρ').





$\phi \rightarrow (\rho\pi) \rightarrow \pi^+\pi^-\pi^0$

Y2K 17 pb^{-1} analysis of Dalitz Plot allowed to extract ρ parameters (m,Γ) for each state of charge and non-ρ contributions (direct, $\omega\pi^0$, ρ′).



parameter	fit(a)
$\chi^2\ [p(\chi^2)]$	1939 [12%]
M_{ρ^0}	
M_{ρ^+}	$775.8 \pm 0.5 \pm 0.3$
M_{ρ^-}	**PDG(2002) =771.1 ± 0.9**
Γ_{ρ^0}	
Γ_{ρ^+}	$143.9 \pm 1.3 \pm 1.1$
Γ_{ρ^-}	**PDG(2002) =149.2 ± 0.7**
a_d	$0.78 \pm 0.09 \pm 0.13$
ϕ_d	$2.47 \pm 0.08 \pm \pm 0.08$
$a_\omega \times 10^3$	$7.1 \pm 0.6 \pm 0.8$
ϕ_ω	$-0.22 \pm 0.11 \pm 0.04$

$\phi \to (\eta'\gamma)/(\eta\gamma) \to \pi^+\pi^- \gamma\gamma\gamma$

BR(f ® h’g)/ BR(f ® hg)=(4.70 ± 0.47 ± 0.31) 10^{-3}
BR(f ® h’g) = (6.10 ± 0.61 ± 0.43) 10^{-5}
PDG 2002 : (6.7 ± 1.5) 10^{-5}

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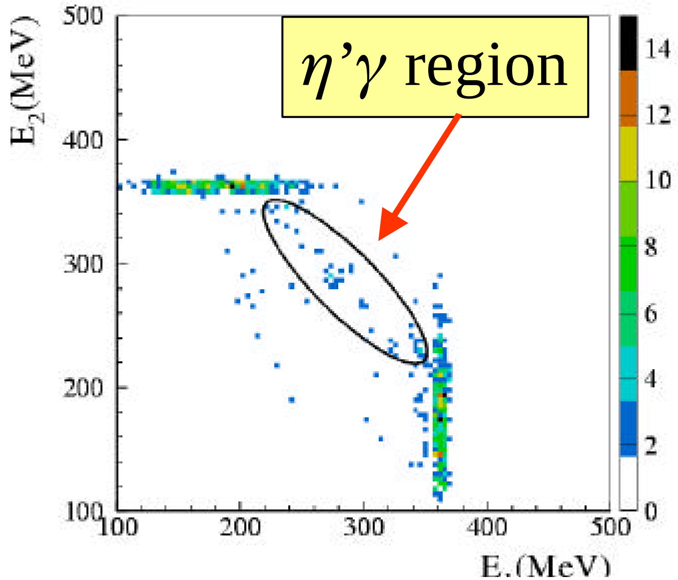
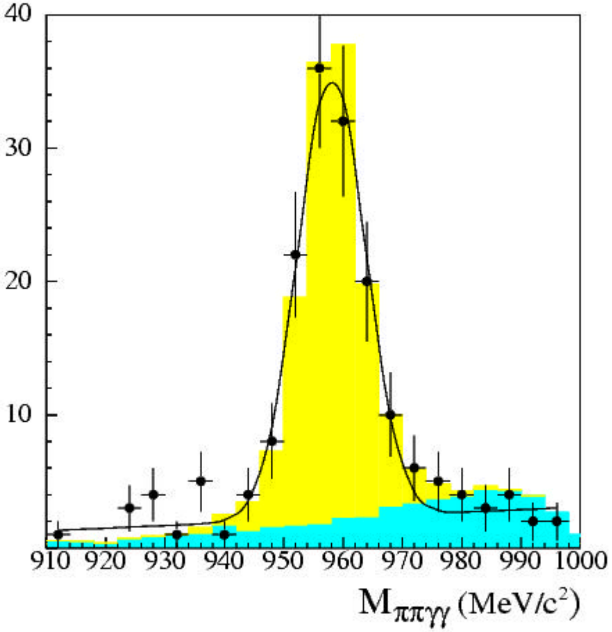


Mixing Angle θ_P

$$R = \cot^2 j_p \left(1 - \frac{m_s}{\bar{m}} \frac{\tan j_v}{\sin 2j_p}\right)^2 \left(\frac{P(h')}{P(h)}\right)^3$$

$$q_p = (-12.9^{+1.9}_{-1.6})^\circ \leftarrow j_p = (41.8^{+1.9}_{-1.6})^\circ$$



Glue content

$$|h(h')\rangle = \frac{X_{h(h')}}{\sqrt{2}}|u\bar{u} + d\bar{d}\rangle + \frac{Y_{h(h')}}{\sqrt{2}}|s\bar{s}\rangle + Z_{h(h')}|g\rangle$$

$$|glue\rangle \le 15\% \leftarrow Z_h^2 = 0.06^{+0.09}_{-0.06}$$

$\phi \rightarrow (\eta'\gamma)/(\eta\gamma) \rightarrow \pi^+\pi^- \gamma\gamma\gamma$

BR(f ® h'g)/ BR(f ® hg)=(4.70 ± 0.47 ± 0.31) 10^{-3}
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Mixing Angle θ_P

$$R = \cot^2 j_p \left(1 - \frac{m_s}{\bar{m}} \frac{\tan j_V}{\sin 2 j_p}\right)^2 \left(\frac{P(h')}{P(h)}\right)^3$$

$$j_p = (41.8^{+1.9}_{-1.6})^\circ$$

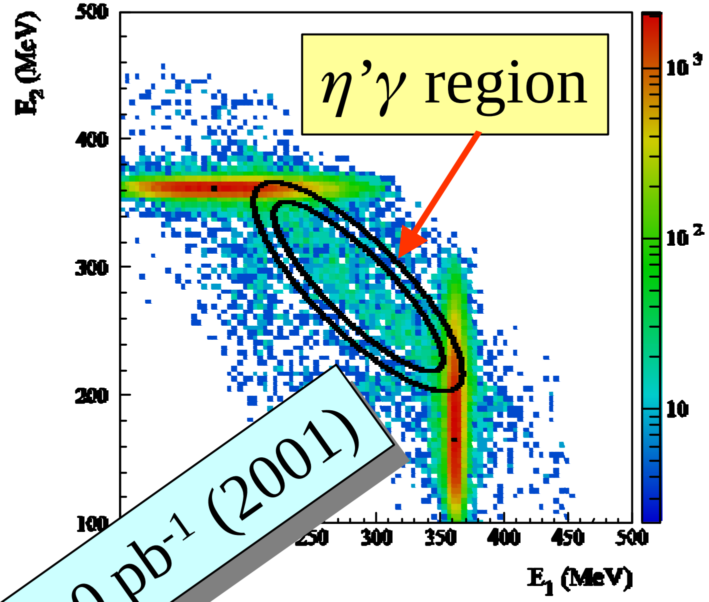
$$q_p = (-12.9^{+1.9}_{-1.6})^\circ$$

Glue content

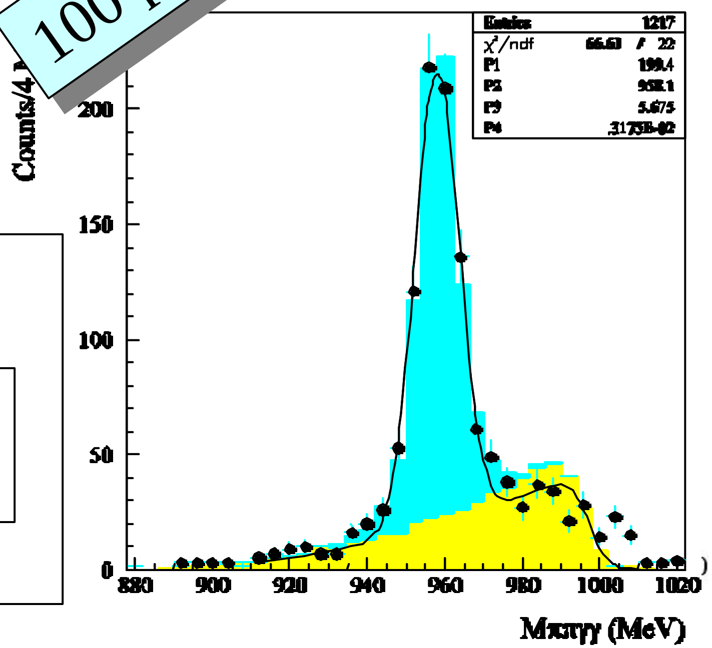
$$|h(h')\rangle = \frac{X_{h(h')}}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle + \frac{Y_{h(h')}}{\sqrt{2}} |s\bar{s}\rangle + Z_{h(h')} |g\rangle$$

$$Z_h^2 = 0.06^{+0.09}_{-0.06}$$

$$|glue\rangle \le 15\%$$



100 pb-1 (2001)



$\phi \rightarrow (f_0\gamma) / (a_0\gamma)$

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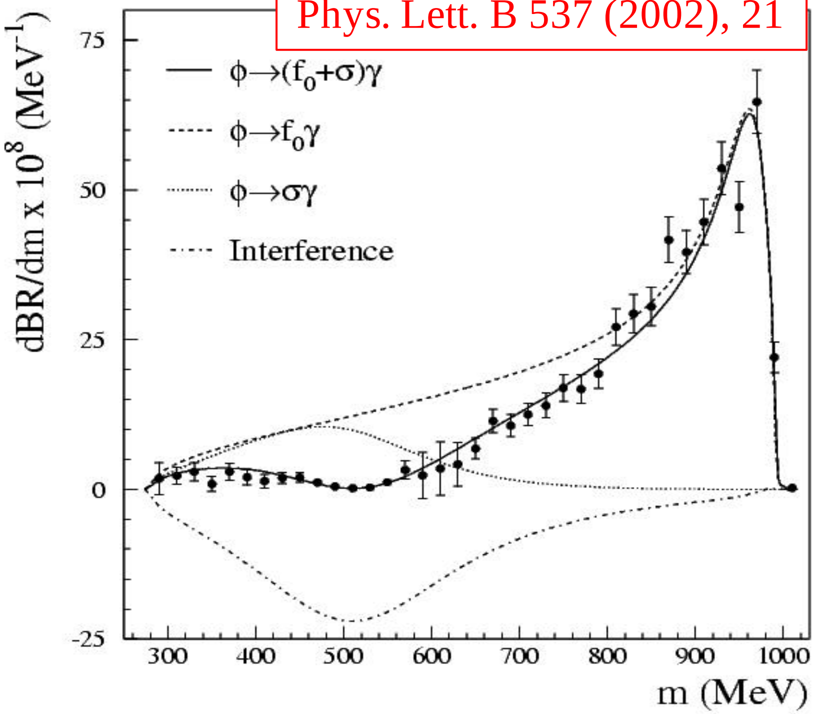
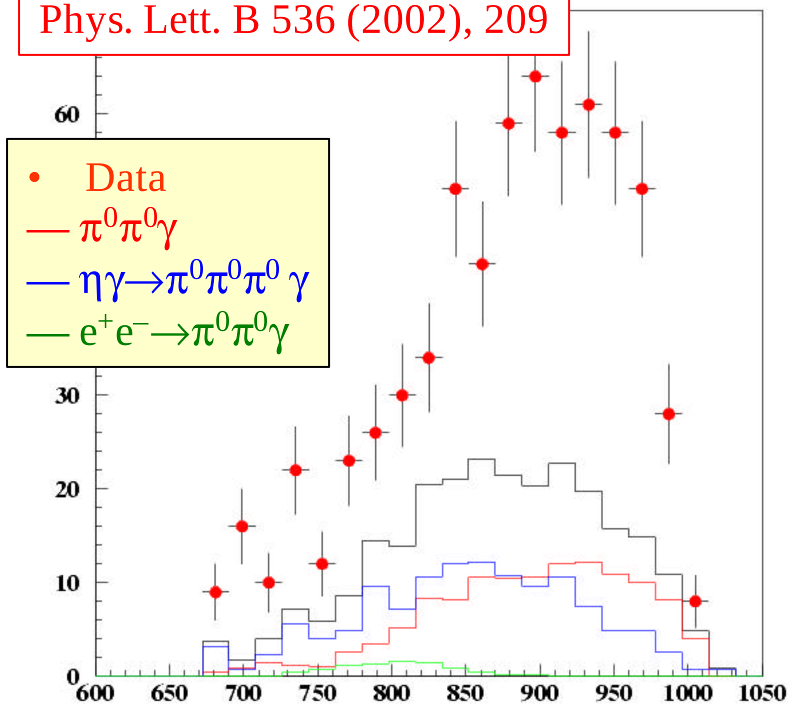


Phys. Lett. B 536 (2002), 209



Mhp⁰ (MeV)

BR(f ®p^{0}p^{0}g) = (1.09 ± 0.03 ± 0.05) 10^{-4}
PDG 2002 : (1.08 ± 0.17 ± 0.09) 10^{-4}

Phys. Lett. **B 537** (2002), 21

BR(f →hp^{0}g) = (0.85 ± 0.05 ± 0.06) 10^{-4}
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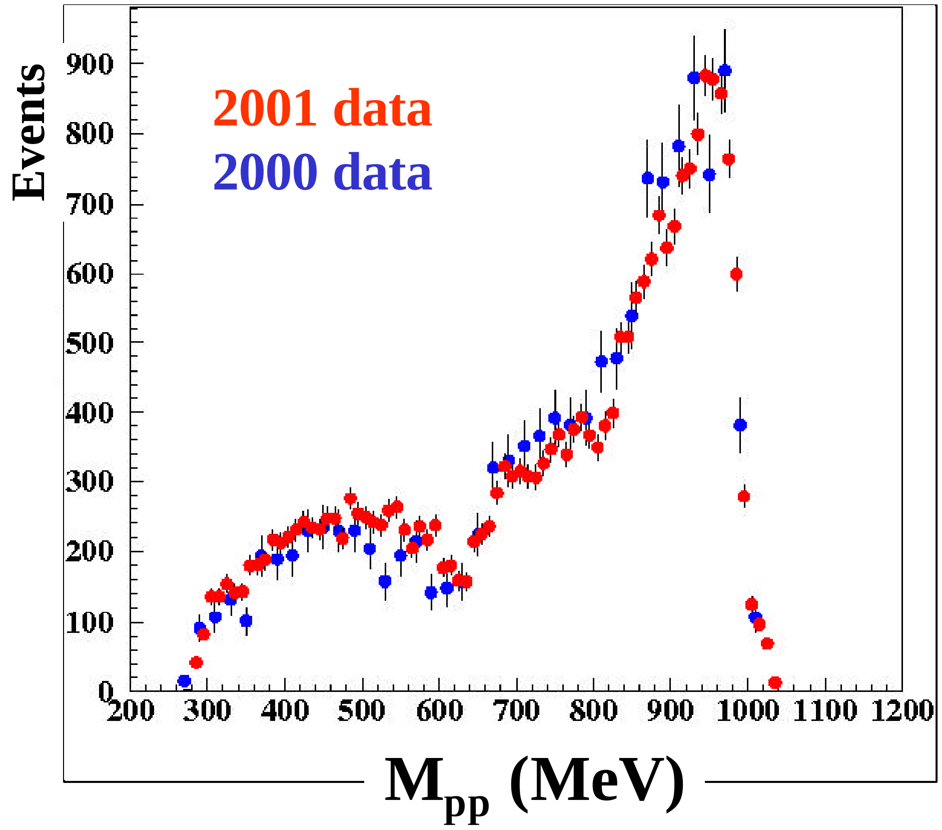
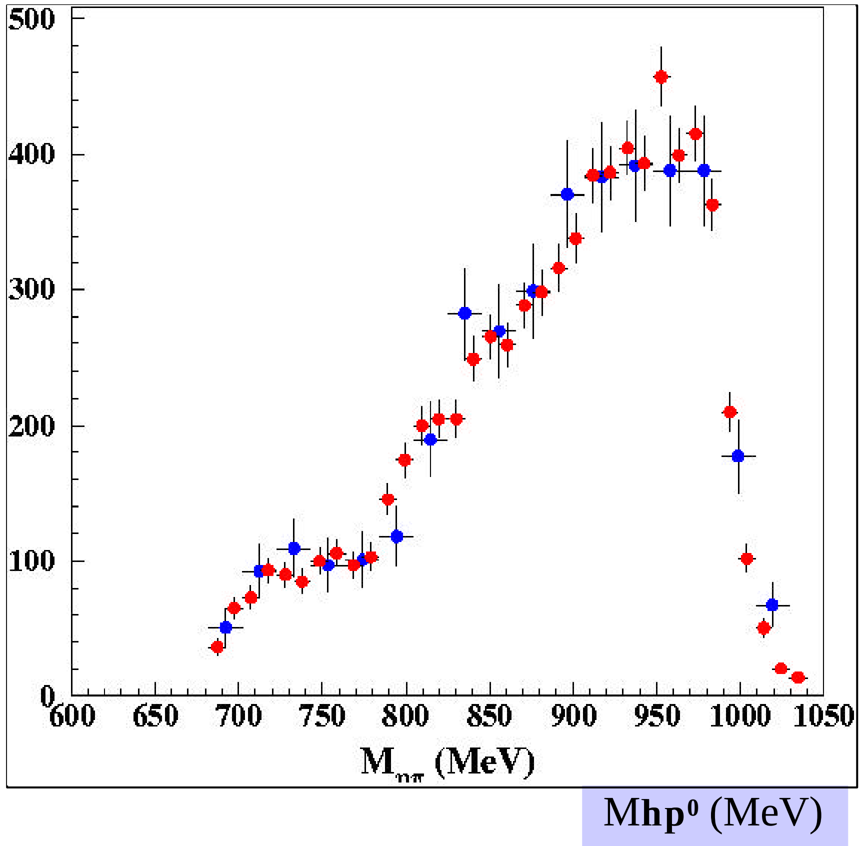
Phys. Lett. **B 536** (2002), 209

$\phi \to (f_0\gamma) / (a_0\gamma)$





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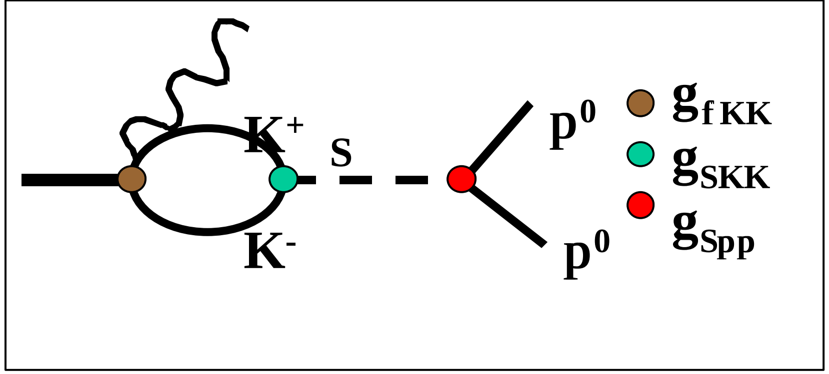
f_0/a_0 Couplings

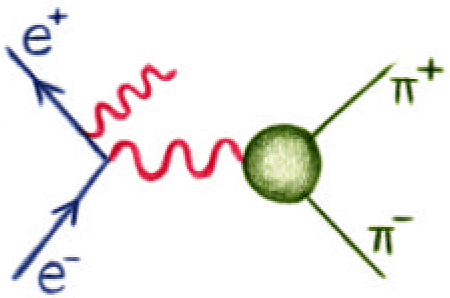


$$\frac{d}{dm}\mathrm{BR}(\Phi \to S\tilde{a} \to \eth^0\eth^0 g) = \frac{2m^2}{\eth}\,\frac{\tilde{A}_{\ddot{o}S\tilde{a}}\tilde{A}_{S\eth^0\eth^0}}{|D_s|^2}\,\frac{1}{\tilde{A}_{\ddot{o}}}$$

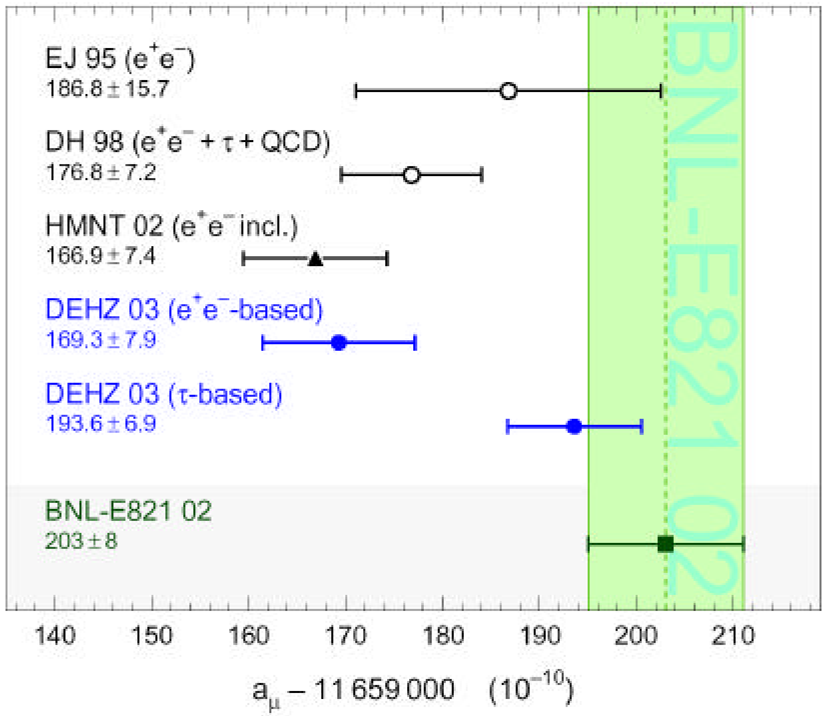
$$\tilde{A}_{\ddot{o}S\tilde{a}}(m) = \frac{g^2_{SK^+K^-}\,g^2_{\ddot{o}K^+K^-}}{12\eth}\,\frac{|g(m)|^2}{M^2_{\ddot{o}}}\left(\frac{M^2_{\ddot{o}} - m^2}{2M_{\ddot{o}}}\right)$$

		KLOE	4q model	$(u\bar{u} \pm d\bar{d})/\sqrt{2}$	$s\bar{s}$	
f_0	$g^2_{KK}/(4\pi)$	2.79 ± 0.12	~ 2.3	~ 0.15	~ 0.30	(GeV^2)
	$g_{\pi\pi}/g_{KK}$	0.50 ± 0.01	~ 0.35	~ 2	~ 0.5	
a_0	$g^2_{KK}/(4\pi)$	0.40 ± 0.04	~ 2.3	~ 0.15	---	(GeV^2)
	$g_{\eta\pi}/g_{KK}$	1.35 ± 0.09	~ 0.9	~ 1.5	---	

- f_0 parameters compatible with 4q model
- a_0 parameters not well described by the 4q model



σ(e⁺e⁻→hadrons)



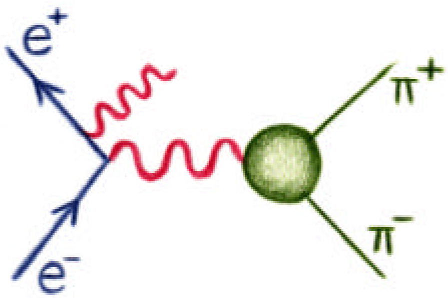
⇨KLOE energy range is responsible for about 67 % of δa_μ and for 17 % of $\delta\alpha(M_Z)$.

⇨Novosibirsk CMD2 direct measurement is at 0.6% level, but disagrees, after CVC rotation, with τ data [Davier *et al.*, *Jan*'03].

$$\sigma^{I=1}_{e+e-\to\pi\pi} = \frac{4\pi\alpha^2}{s}\,\frac{m_\tau^2}{6S_{EW}|V_{ud}|^2}\,\frac{BR(\tau\to\pi\pi^0\nu_\tau)}{BR(\tau\to e\nu_e\nu_\tau)}\left[\left(1-\frac{s}{m_\tau^2}\right)^2\left(1+\frac{2s}{m_\tau^2}\right)\right]^{-1}\frac{1}{N}\frac{dN}{ds}$$

⇨ KLOE has analyzed 2001 data. Statistical errors are already at the 0.2% level. Systematic effects are still at 2%, being further investigated.

⇨Present goal is the measurement of the hadronic cross section at level of 1 %.



$\sigma(e^+e^- \rightarrow \text{hadrons})$

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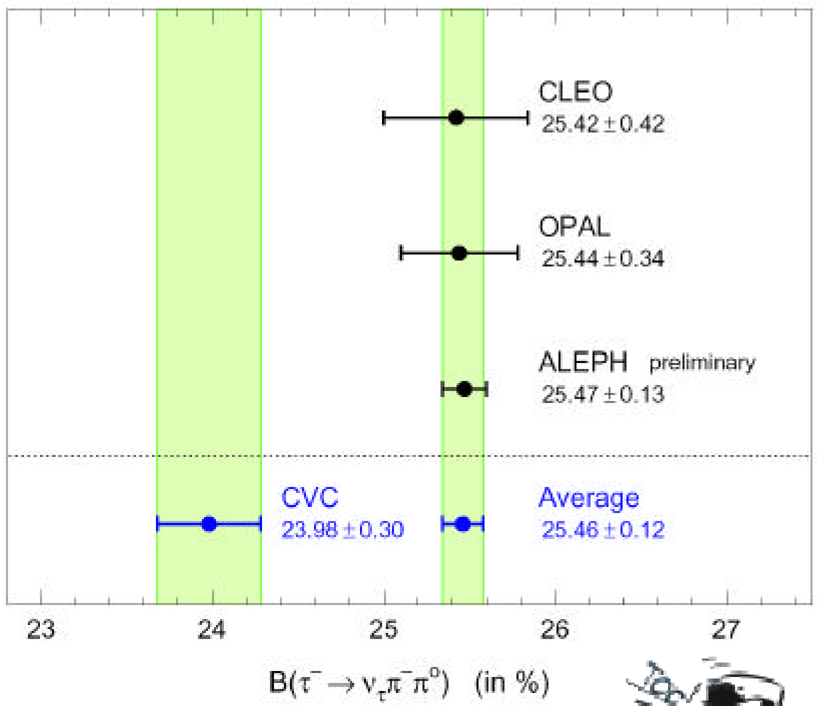

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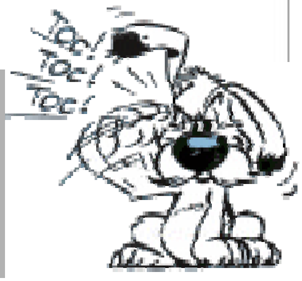

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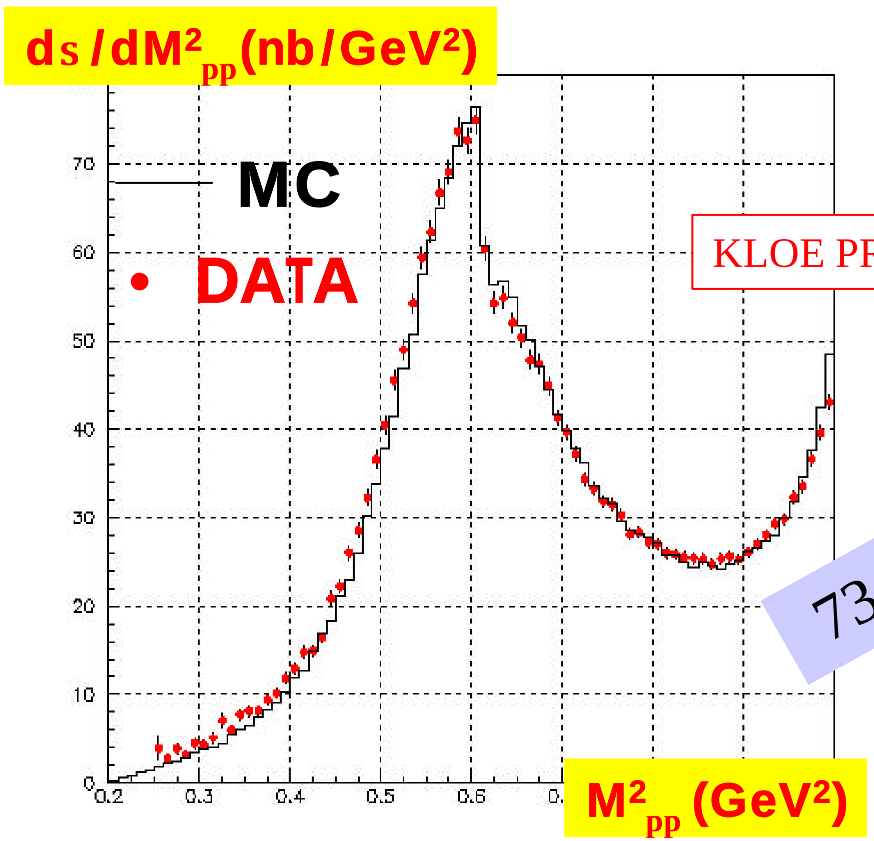
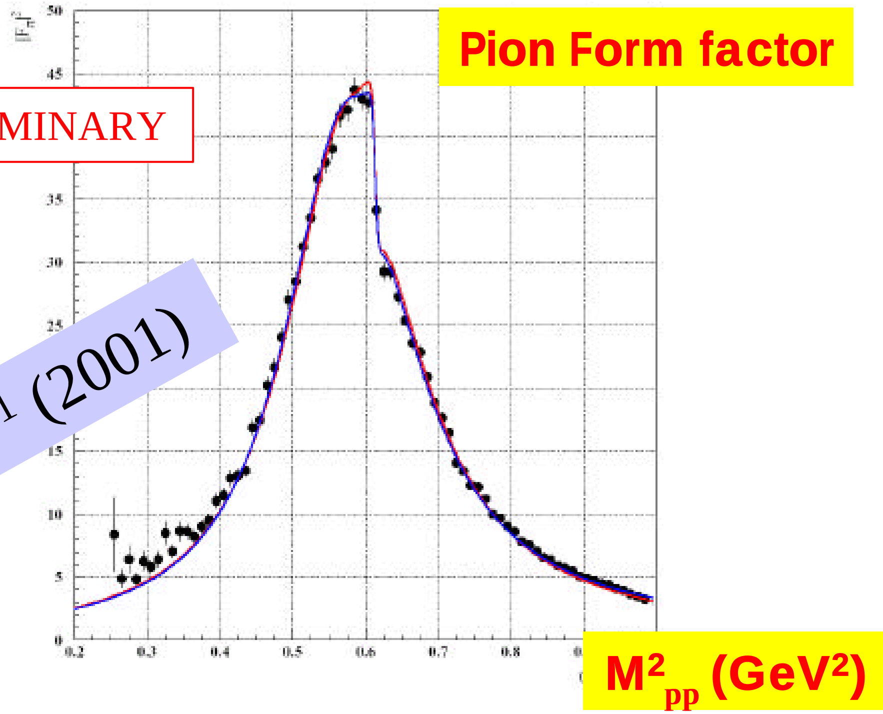
Preliminary Comparisons



$$|F_\pi(M^2_{\pi\pi})|^2 \approx \frac{1}{H(M^2_{\pi\pi})}\frac{d\sigma(e^+e^-\to\pi^+\pi^-\gamma)}{dM^2_{\pi\pi}}$$



KLOE 2001 data compared with the MC generator **PHOKHARA (NLO)** [Kuhn *et al.* '02], that is expected to be accurate at 0.5% level (should still improve on FSR description).

KLOE DATA compared with parametrization of direct √s SCAN performed by CMD2 at Novosibirsk.

Prospects for the future

Plans for 2003

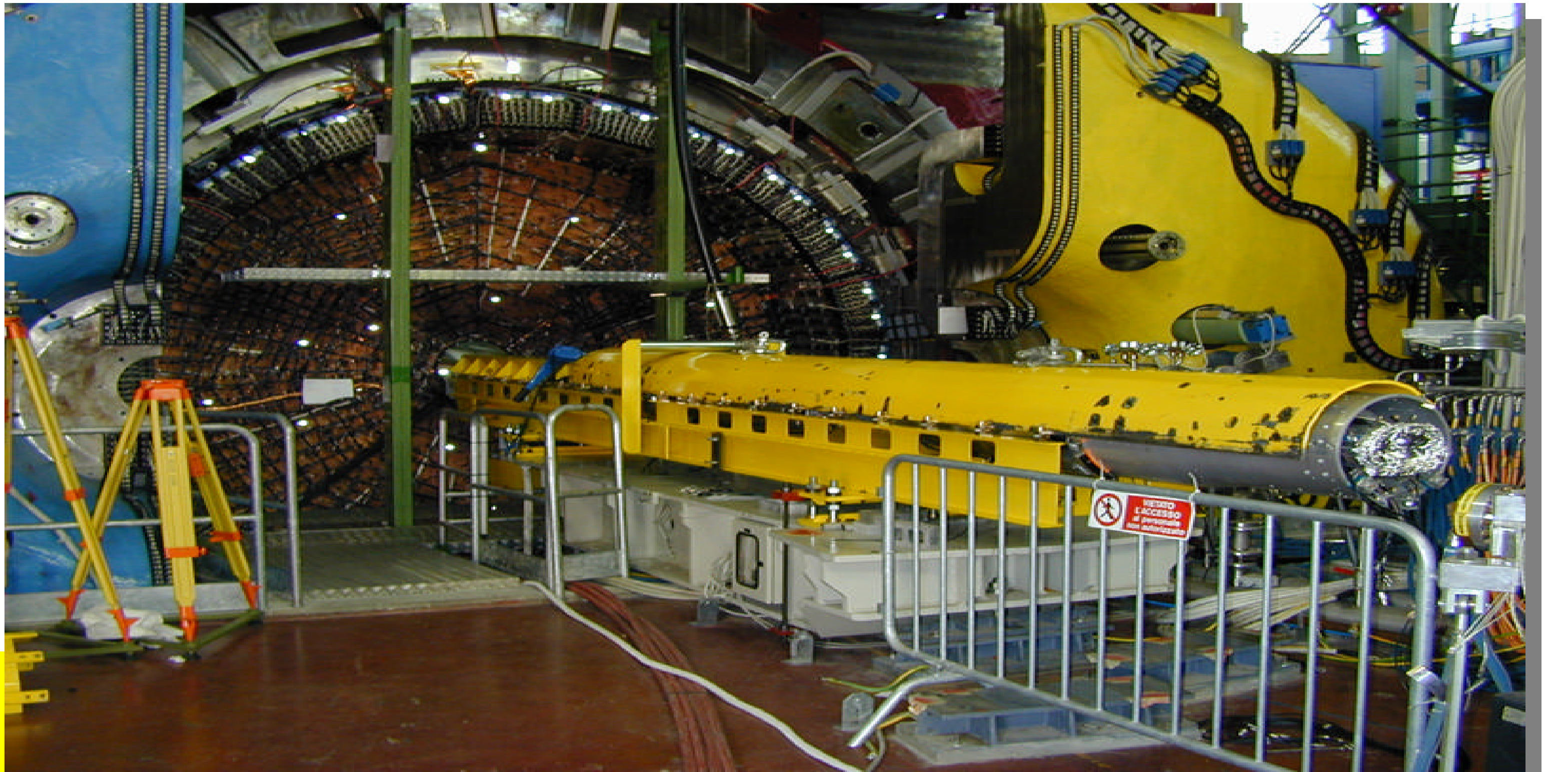
DAFNE

- Increase peak luminosity and reach 1.5 10^{32} $cm^{-2}s^{-1}$
- Restart by May 2003 with FINUDA first
- Deliver successively about 1 fb^{-1} to KLOE

KLOE

- Install new interaction region to ease DAΦNE operation
- Show ε'/ε capability
- K^0, $K^{\pm}$ Branching ratios, V_{us}
- Hadronic cross section

Plans for 2003



KLOE

- Install new interaction region to ease DAΦNE operation
- Show ε’/ε capability
- K^0, $K^{\pm}$ Branching ratios, V_{us}
- Hadronic cross section

Conclusions

✓Many analyses are about to be finalized

✓K_s are ready for ε'/ε at $5 \cdot 10^{-4}$ level

✓K_s leptonic asymmetries OK

✓K_L need at least 10 times more data to get ε'/ε at $5 \cdot 10^{-4}$ level

✓K_L BRs currently at 2% level

✓1 fb^{-1} expected for next run