KLOE results on the f_0, a_0 scalars and on η decays

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La Thuile – Feb 27th – March 5th 2005

Outline

- Study of the a_0 meson
- Study of the f_0 meson
- Dynamics of $\eta \to \pi\pi\pi$ decay
- BR of $\eta \to \pi^0\gamma\gamma$ decay
- Mixing angle of $\eta - \eta'$ system
- Upper limit on $\eta \to \pi^+\pi^-$
- Upper limit on $\eta \to \gamma\gamma\gamma$

Light scalar mesons at KLOE

$$e^+e^- \rightarrow \phi \rightarrow \gamma + f_0(980) \ (I=0) \rightarrow \pi^+\pi^-, \ \pi^0\pi^0$$

$$e^+e^- \rightarrow \phi \rightarrow \gamma + a_0(980) \ (I=1) \rightarrow \eta\,\pi^0, \quad \eta \rightarrow \gamma\gamma, \ \pi^+\pi^-\pi^0$$

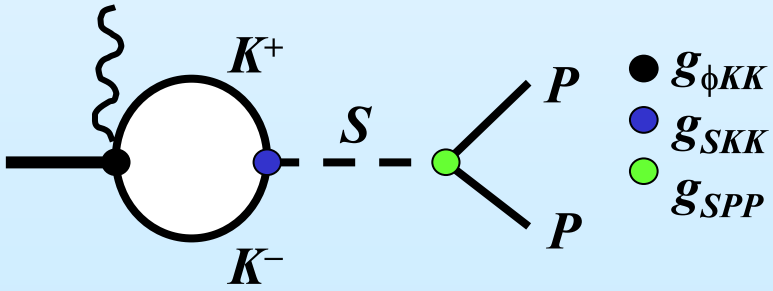
a_0, f_0 : standard q-qbar mesons, 4q mesons, KK molecules ??

The nature of the scalars

- Properties of light scalars can be investigated through the couplings to the ϕ (i.e. to the s quark) and the Dalitz plot of the final three body PPγ final state. We use two models:

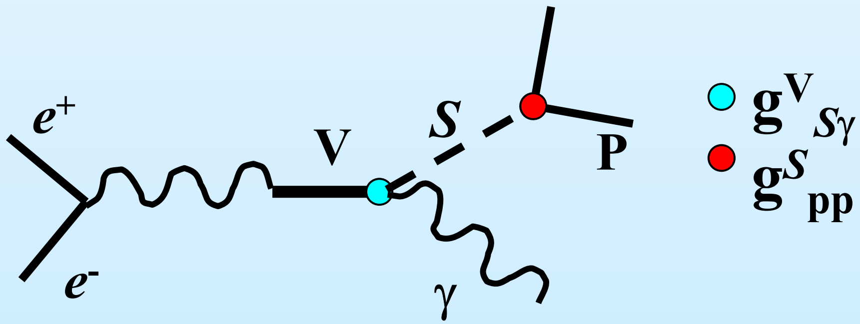
1) Kaon loop

(Achasov,Ivanchenko NPB315 (1989) 465)



2) "No Structure"

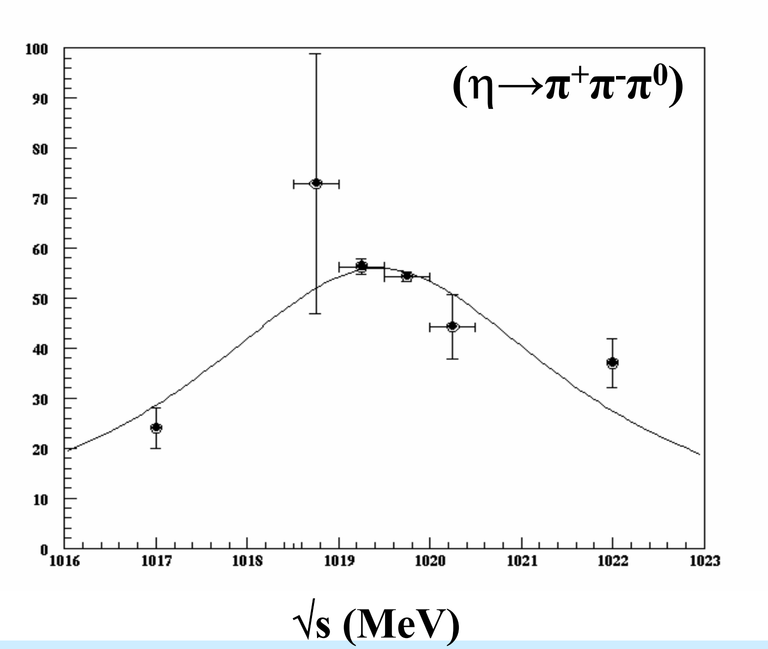
(Isidori-Maiani, private comunication)

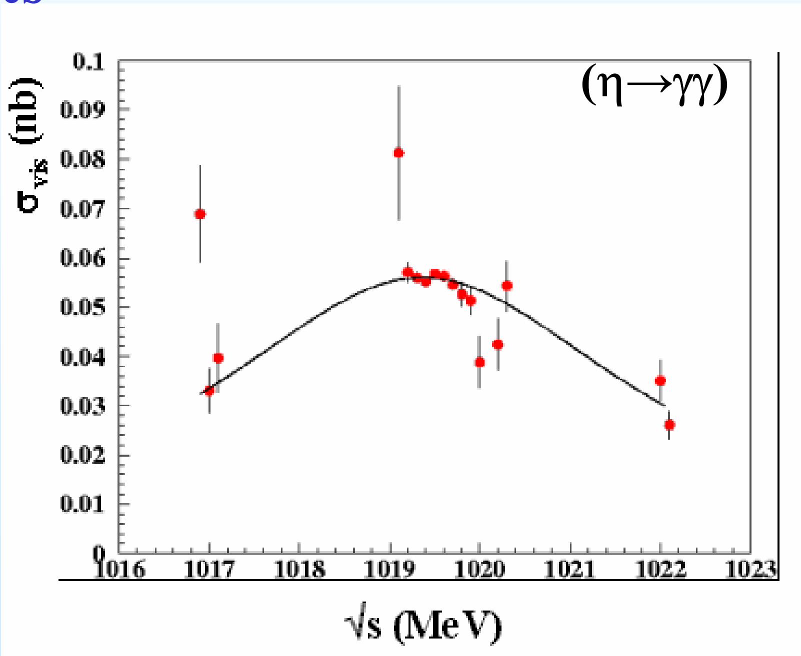


$a_0(980) \rightarrow \eta\pi^0$

2001-2002 data: 395 pb^{-1} at ϕ peak + 10 pb^{-1} at 1017 and 1022 MeV

1) $\eta \rightarrow \gamma\gamma$ (39.43%) 2.2×10^4 events
2) $\eta \rightarrow \pi^+\pi^-\pi^0$ (22.6%) 4180 events





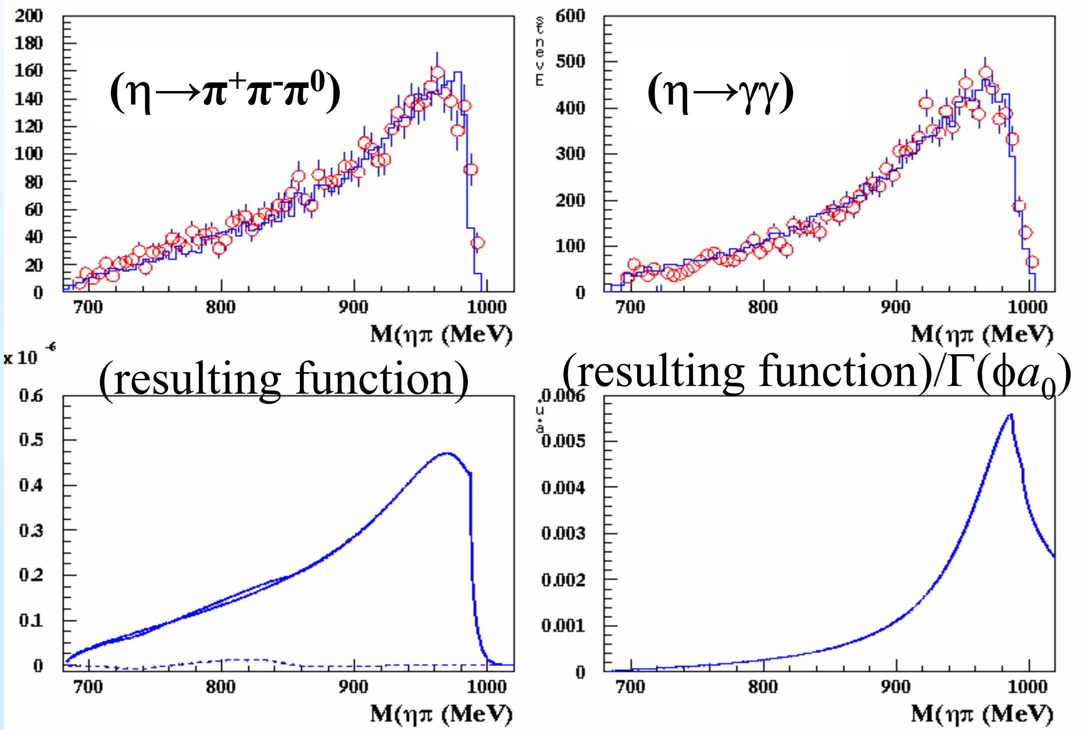
Fit to the Mηπ spectrum

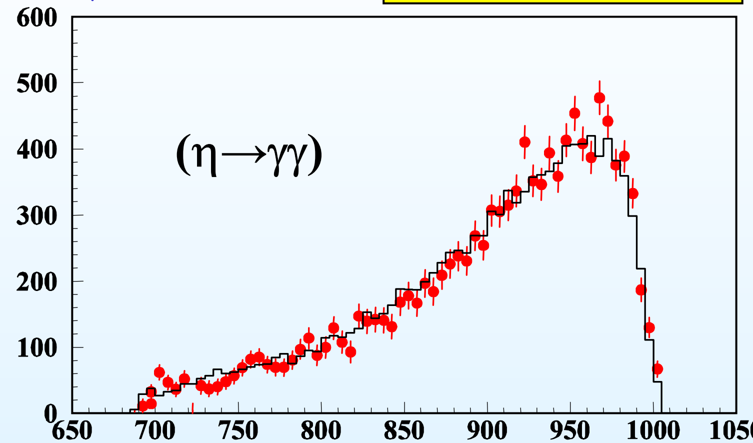
$$\frac{d\sigma}{dm} \propto \left| \left(\phi \to a_0\gamma \to \eta\pi^0\gamma\right) + \left(\phi \to \rho\pi^0 \to \eta\pi^0\gamma\right) \right|^2$$

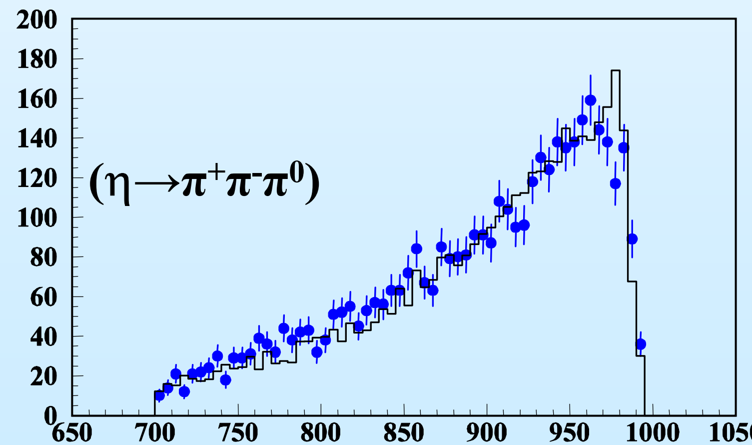
No structure

Kaon Loop

Evts/5 MeV







$M_{\eta\pi}$ (MeV)

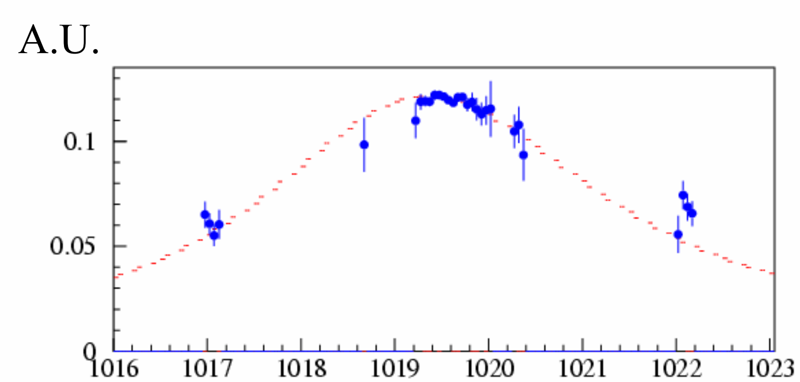
$f_0(980) \to \pi^0 \pi^0$

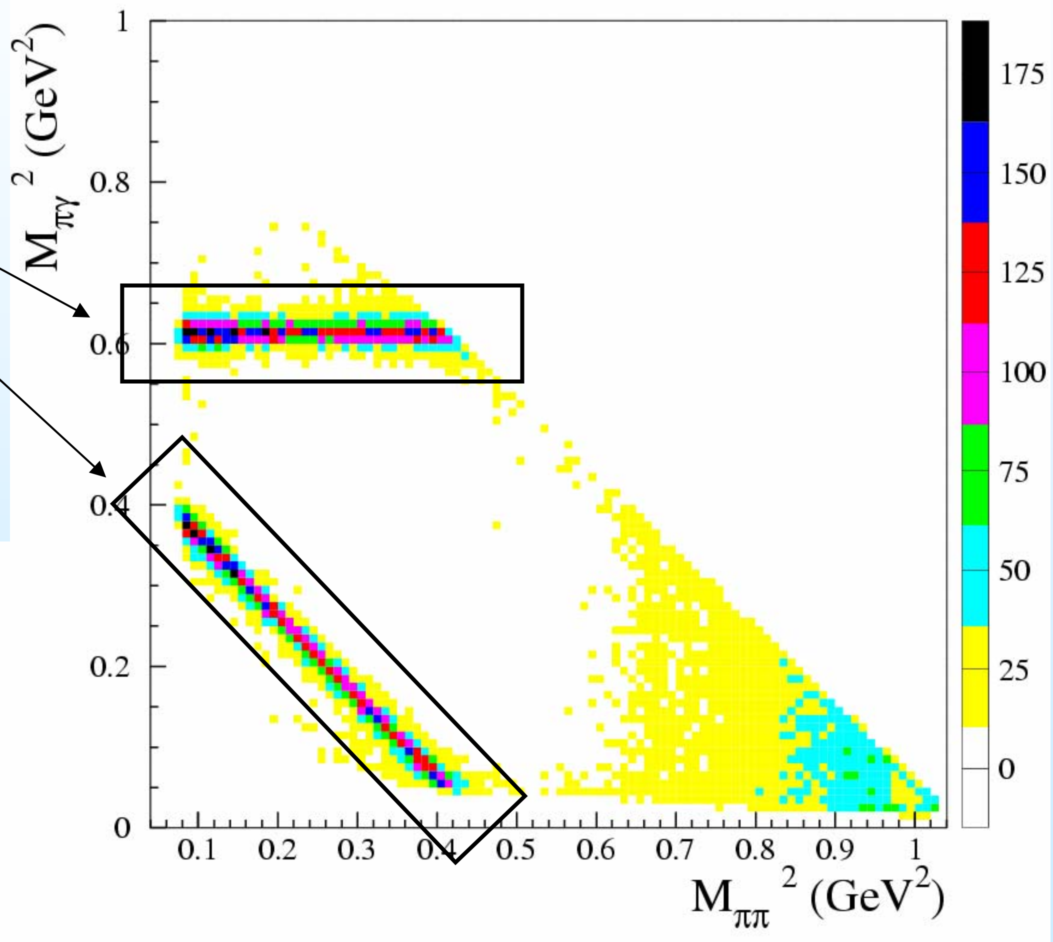
Two main contributions to $\pi^0\pi^0\gamma$ final state @ M_ϕ:

1. $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$
   $\sigma_{vis}(M_\phi) \sim 0.5$ nb

2. $\phi \to S\gamma \to \pi^0\pi^0\gamma$
   $\sigma_{vis}(M_\phi) \sim 0.3$ nb

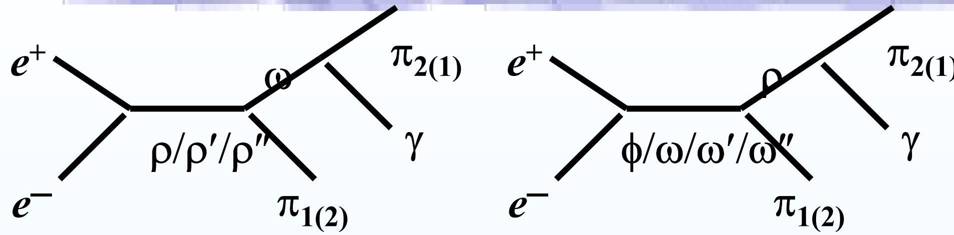
Data: 450 pb^{-1} from 2001 – 2002 data taking



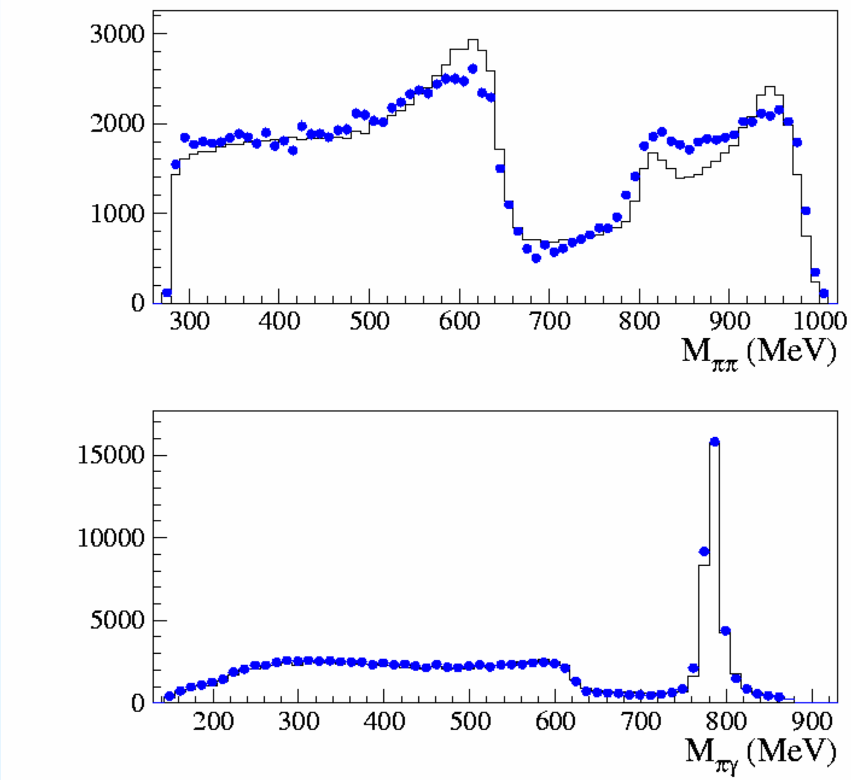


Kaon loop (+VDM) fit

VDM:



+ interference terms



The Achasov fit function

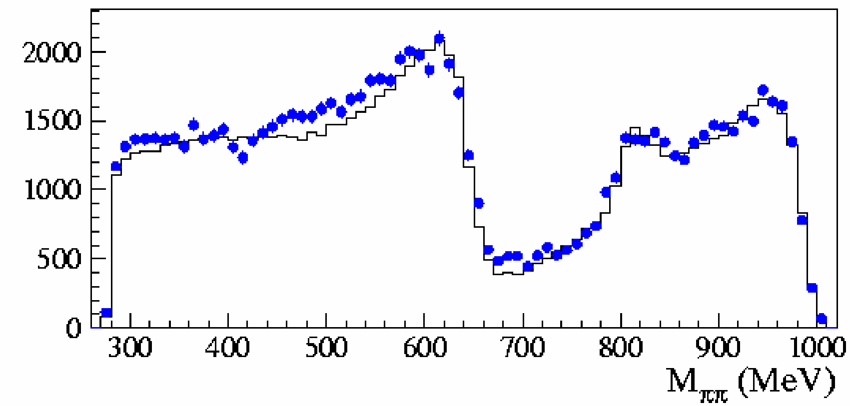
$$
\begin{aligned}
\frac{d\sigma(e^+e^-\to\pi^0\pi^0\gamma)}{dm\,dm_{\pi\gamma}} = \frac{\alpha m_{\pi\gamma} m}{3(4\pi)^2 s^3}\Bigg\{ & \frac{2g^2_{\phi\gamma}}{|D_\phi(s)|^2}|g(m)|^2\left|\frac{g_{f_0K^+K^-}g_{f_0\pi^0\pi^0}}{D_{f_0}(m)}\right|^2 + \\
& \frac{1}{16}F_1(m^2,m^2_{\pi\gamma})\left|\left(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\right)\frac{e^{i\delta_{b\rho}}}{D_\rho(m^2_{\pi\gamma})}+\frac{C_{\omega\pi^0}}{D_\omega(m^2_{\pi\gamma})}\right|^2 + \\
& \frac{1}{16}F_1(m^2,\tilde{m}^2_{\pi\gamma})\left|\left(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\right)\frac{e^{i\delta_{b\rho}}}{D_\rho(\tilde{m}^2_{\pi\gamma})}+\frac{C_{\omega\pi^0}}{D_\omega(\tilde{m}^2_{\pi\gamma})}\right|^2 + \\
& \frac{1}{8}F_2(m^2,m^2_{\pi\gamma})Re\Bigg[\left(\left(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\right)\frac{e^{i\delta_{b\rho}}}{D_\rho(m^2_{\pi\gamma})}+\frac{C_{\omega\pi^0}}{D_\omega(m^2_{\pi\gamma})}\right)\times \\
& \left(\left(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\right)\frac{e^{i\delta_{b\rho}}}{D_\rho(\tilde{m}^2_{\pi\gamma})}+\frac{C_{\omega\pi^0}}{D_\omega(\tilde{m}^2_{\pi\gamma})}\right)^*\Bigg] \mp \\
& \frac{1}{\sqrt{2}}Re\Bigg[g(m)e^{i\delta_B(m)}\frac{g_{f_0K^+K^-}g_{f_0\pi^0\pi^0}}{D_{f_0}(m)}\frac{g_{\phi\gamma}}{D_\phi(s)}\Bigg(\\
& F_3(m^2,m^2_{\pi\gamma})\left(\left(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\right)\frac{e^{i\delta_{b\rho}}}{D_\rho(m^2_{\pi\gamma})}+\frac{C_{\omega\pi^0}}{D_\omega(m^2_{\pi\gamma})}\right)^* + \\
& F_3(m^2,\tilde{m}^2_{\pi\gamma})\left(\left(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\right)\frac{e^{i\delta_{b\rho}}}{D_\rho(\tilde{m}^2_{\pi\gamma})}+\frac{C_{\omega\pi^0}}{D_\omega(\tilde{m}^2_{\pi\gamma})}\right)^*\Bigg)\Bigg]\Bigg\},
\end{aligned}
$$

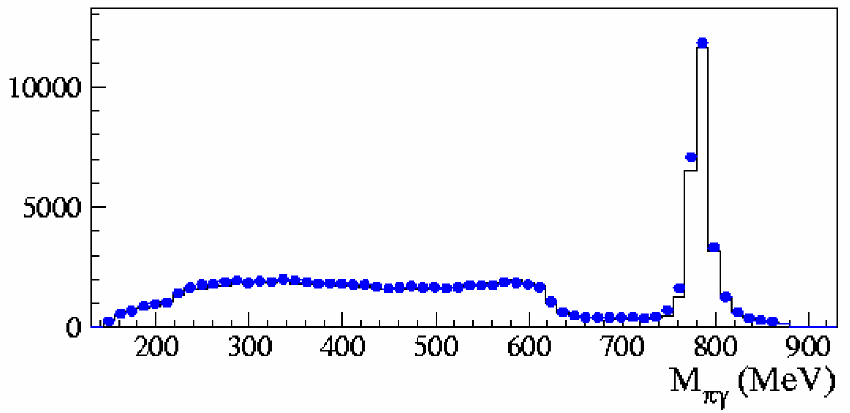
[N.N.Achasov, A.V.Kiselev, private communication]

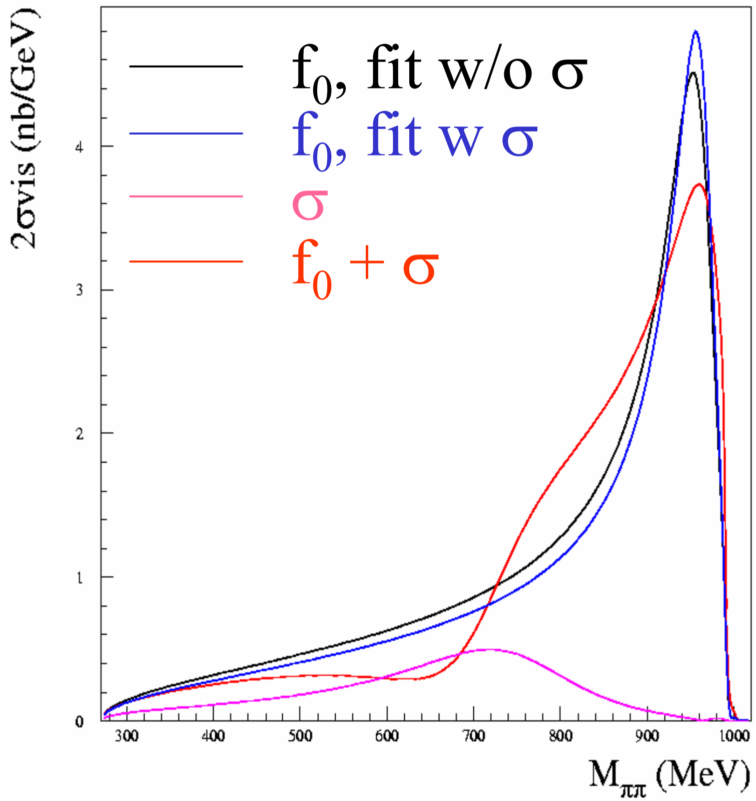
Fit includes only statistical errors

Do we need a σ(600) ?

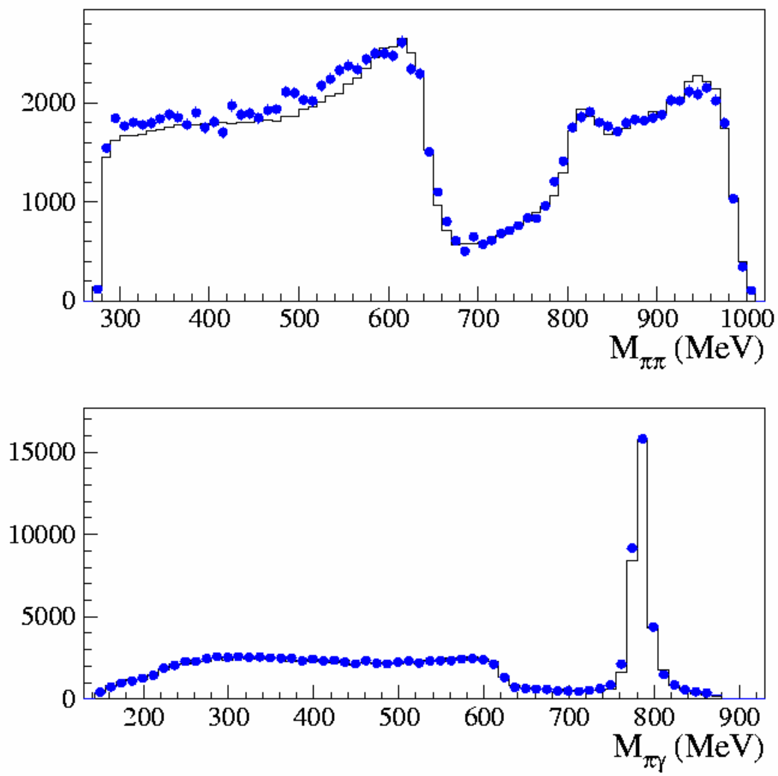
Kaon loop fit including σ(600)

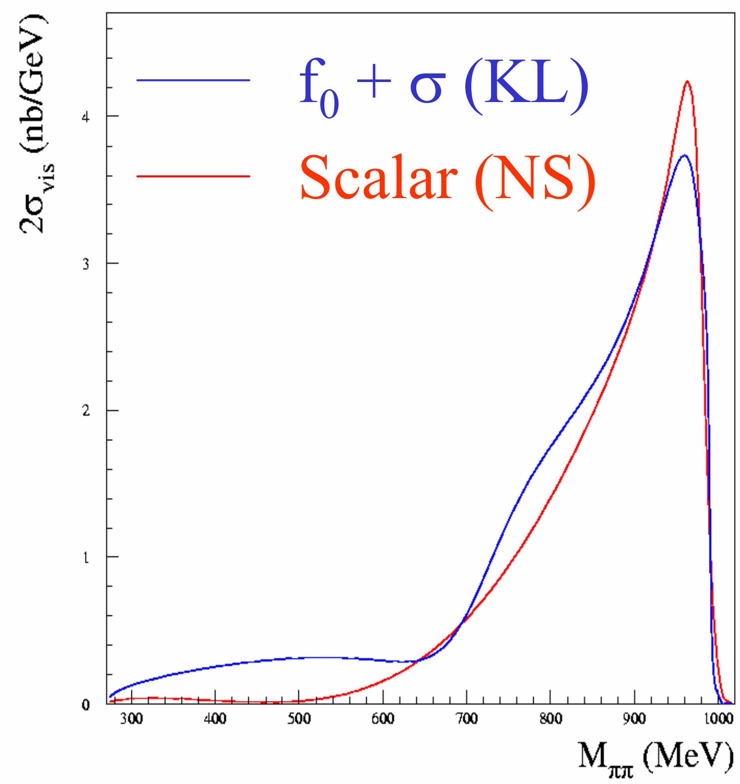






"No structure" (+VDM) fit

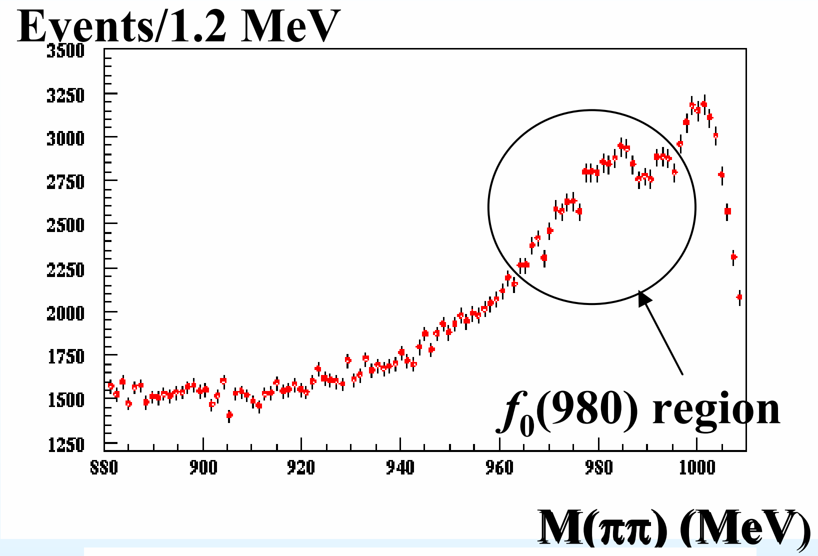




Fit includes only statistical errors

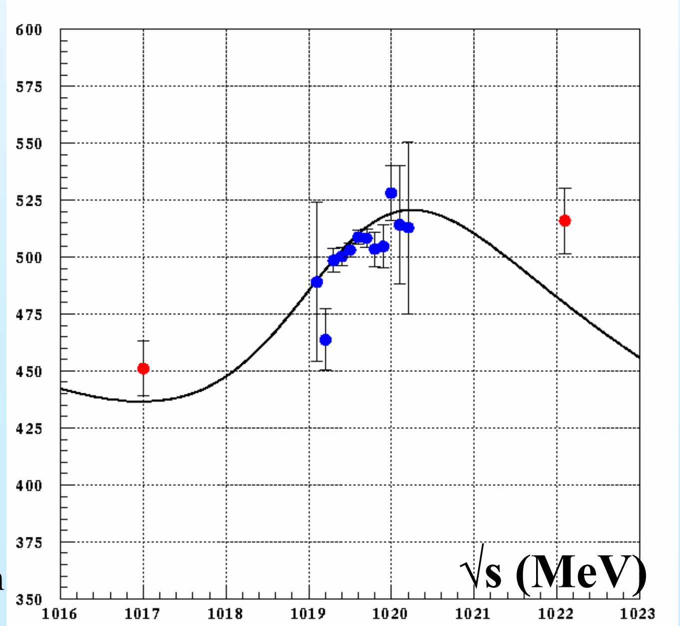
$f_0(980)\to\pi^+\pi^-$

- $e^+e^-\to\pi^+\pi^-\gamma$ events with the photon at large angle ($45°<\vartheta_\gamma<135°$)
- Main contributions:
  ISR (radiative return to ρ, ω)
  FSR
- Search for the f_0 signal as a deviation on $M(\pi^+\pi^-)$ spectrum from the expected ISR + FSR shape

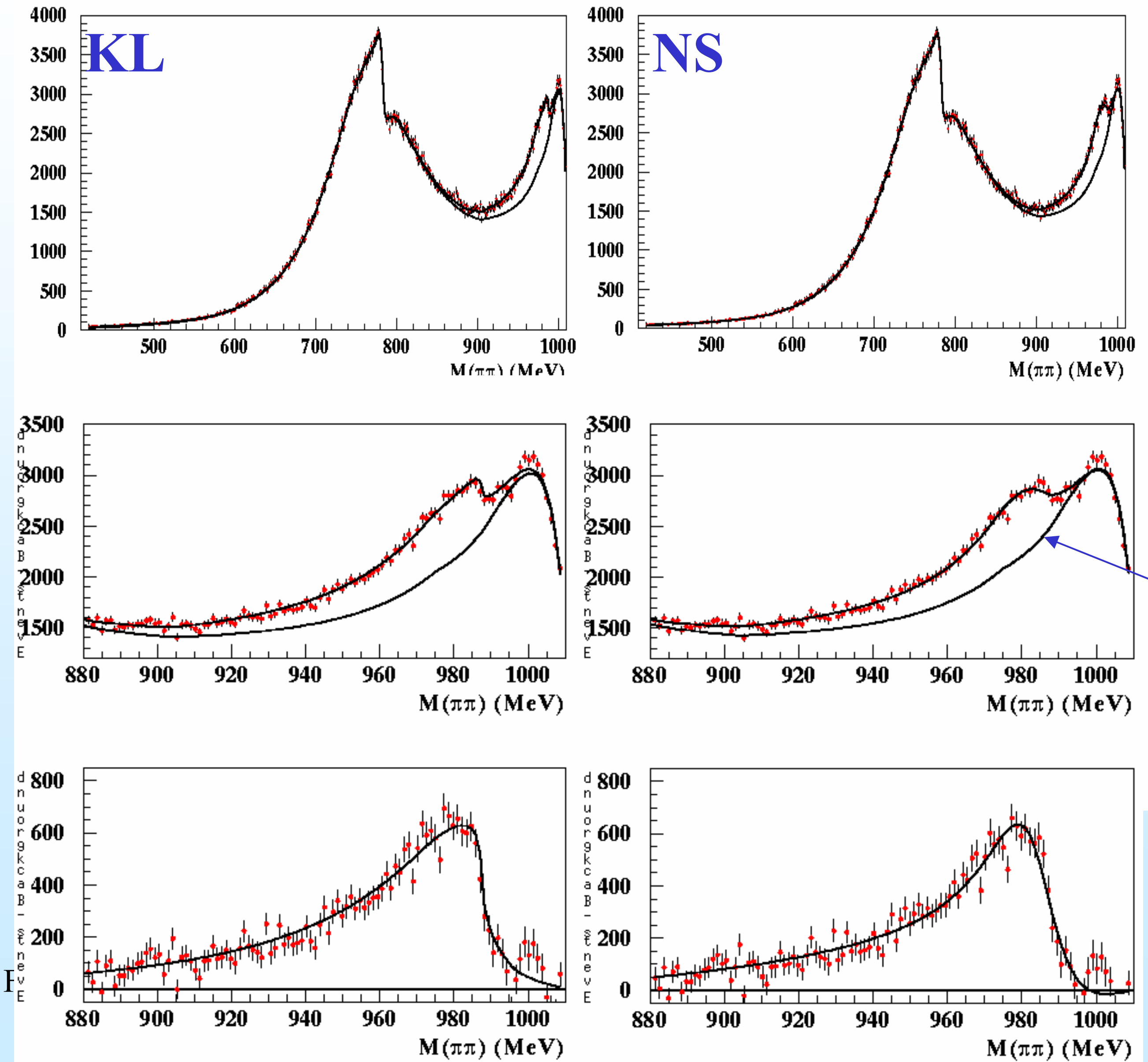


- 676,000 events selected

- Good "resonant" behaviour for events in signal region (900-1000 MeV)



Fit results



Full spectrum

Signal region

ISR+FSR

Spectrum – (ISR+FSR)

The coupling to the ϕ

In the "no structure" approach the crucial parameter is the coupling of the scalars to the ϕ

Meson	$g_{\phi M\gamma}$ (GeV^{-1})
π^0	0.12
η	0.66
η'	0.70
a_0	1.3
f_0	1.8 – 2.3

Increasing strange quark content

???

$\eta \to 3\pi$ in chiral theory

The decay $\eta \to 3\pi$ occours primarily on account of the d-u quark mass differences and the result arising from lowest order chiral pertubation theory is well known:

$$A(s,t,u) = \frac{1}{Q^2}\frac{m_K^2}{m_\pi^2}(m_\pi^2 - m_K^2)\frac{M(s,t,u)}{3\sqrt{3}F_\pi^2}$$

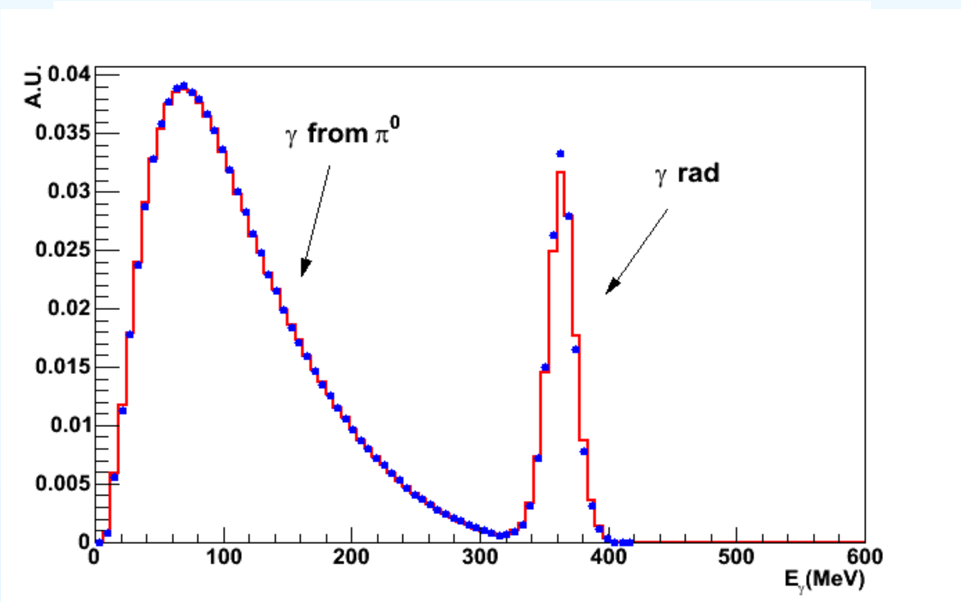
With: $$Q^2 \equiv \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$$ And, at l.o. $$M(s,t,u) = \frac{3s - 4m_\pi^2}{m_\eta^2 - m_\pi^2}$$

A good understanding of M(s,t,u) can *in principle* lead to a very accurate determination of Q:

$$\Gamma(\eta \to 3\pi) \propto |A|^2 \propto Q^{-4}$$

$\eta \to 3\pi$ at KLOE

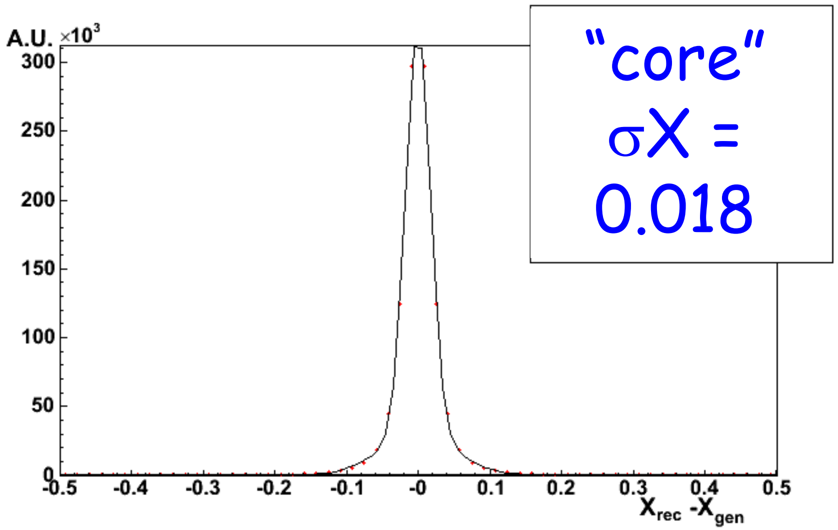
At KLOE η is produced in the process $\phi \to \eta\gamma$.
The final state for $\eta \to \pi^+\pi^-\pi^0$ is thus $\pi^+\pi^-\gamma\gamma$, and the final state for $\eta \to \pi^0\pi^0\pi^0$ is 7γ, both with almost no physical background.

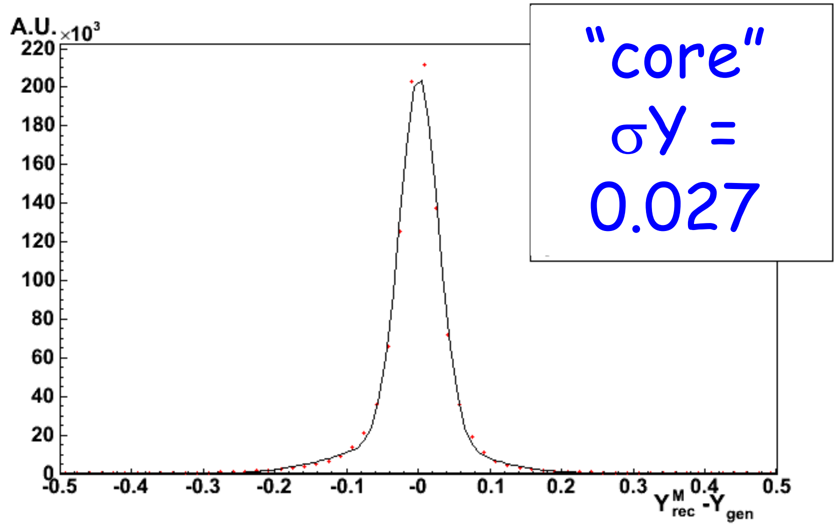


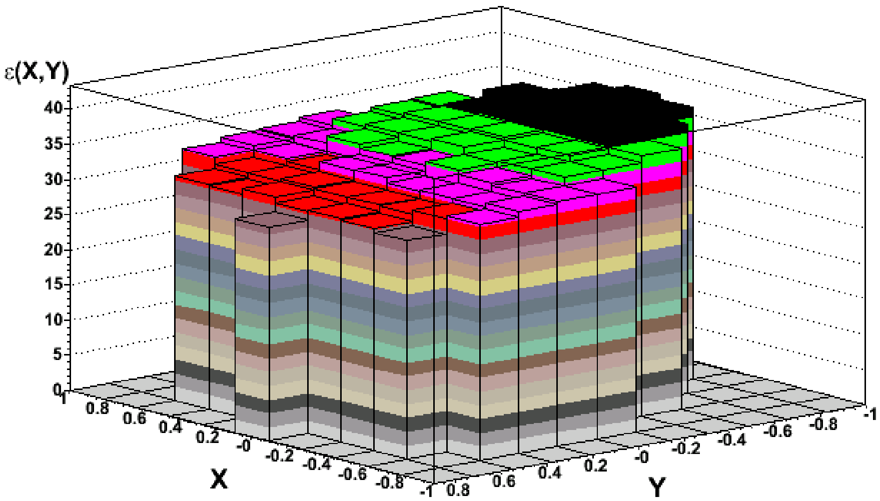
$\pi^+\pi^-\pi^0$ selection:
- 2 track vertex+3 γ candidates
- Kinematic fit

$\pi^0\pi^0\pi^0$ selection:
- 7 γ candidates
- Kinematic fit

$\pi^+\pi^-\pi^0$:resolutions and efficiency



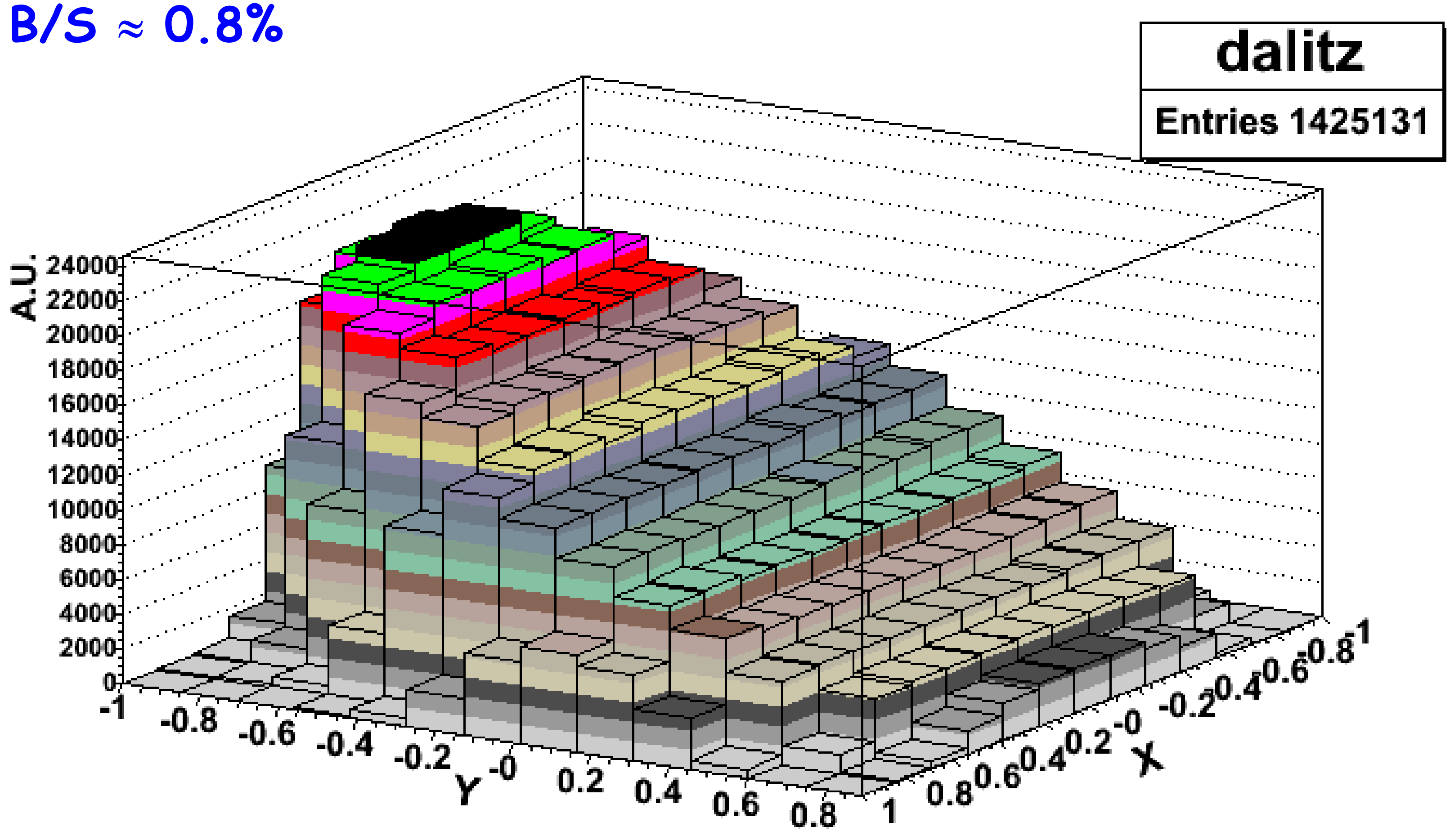




Efficiency almost flat, and ≈ 36%

Signal

B/S ≈ 0.8%



dalitz
Entries 1425131
A.U.
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-1
-0.8
-0.6
-0.4
-0.2
-0
0.2
0.4
0.6
0.8
1
Y
X

Results

$$|A(X,Y)|^2 = 1+aY+bY^2+cX+dX^2+eXY+fY^3$$

ndf	$P_{\chi 2}$ %	a	b	c	d	e	f
147	60	-1.072 ± 0.006 -0.007 +0.005	0.117 ± 0.006 -0.006 +0.004	0.0001 ± 0.0029 -0.0021 +0.0003	0.047 ±0.006 -0.005 +0.004	-0.006 ±0.008 -0. +0.013	0.13 ±0.01 -0.01 +0.02
150	**63**	**-1.072 ± 0.005 -0.008 +0.005**	**0.117 ± 0.006 -0.006 +0.004**	---	**0.047 ±0.006 -0.005 +0.004**	...	**0.13 ±0.01 -0.01 +0.02**
150	0.02	-1.055 ± 0.004 -0.007 +0.006	0.100± 0.005 -0.002 +0.004	---	---	---	0.12 ±0.01 -0.02 +0.02
150	0	-1.013 ± 0.003 -0.007 +0.004	0.120 ± 0.005 -0.023 +0.	---	0.043 ±0.006 -0.003 +0.004	---	---

Results (II)

$|A(X,Y)|^2 = 1-1.072\,Y+0.117\,Y^2+0.047\,X^2+0.13Y^3$

Using preliminary KLOE results shown at ICHEP 04

B.V. Martemyanov and V.S. Sopov (hep-ph\0502023) have extracted:

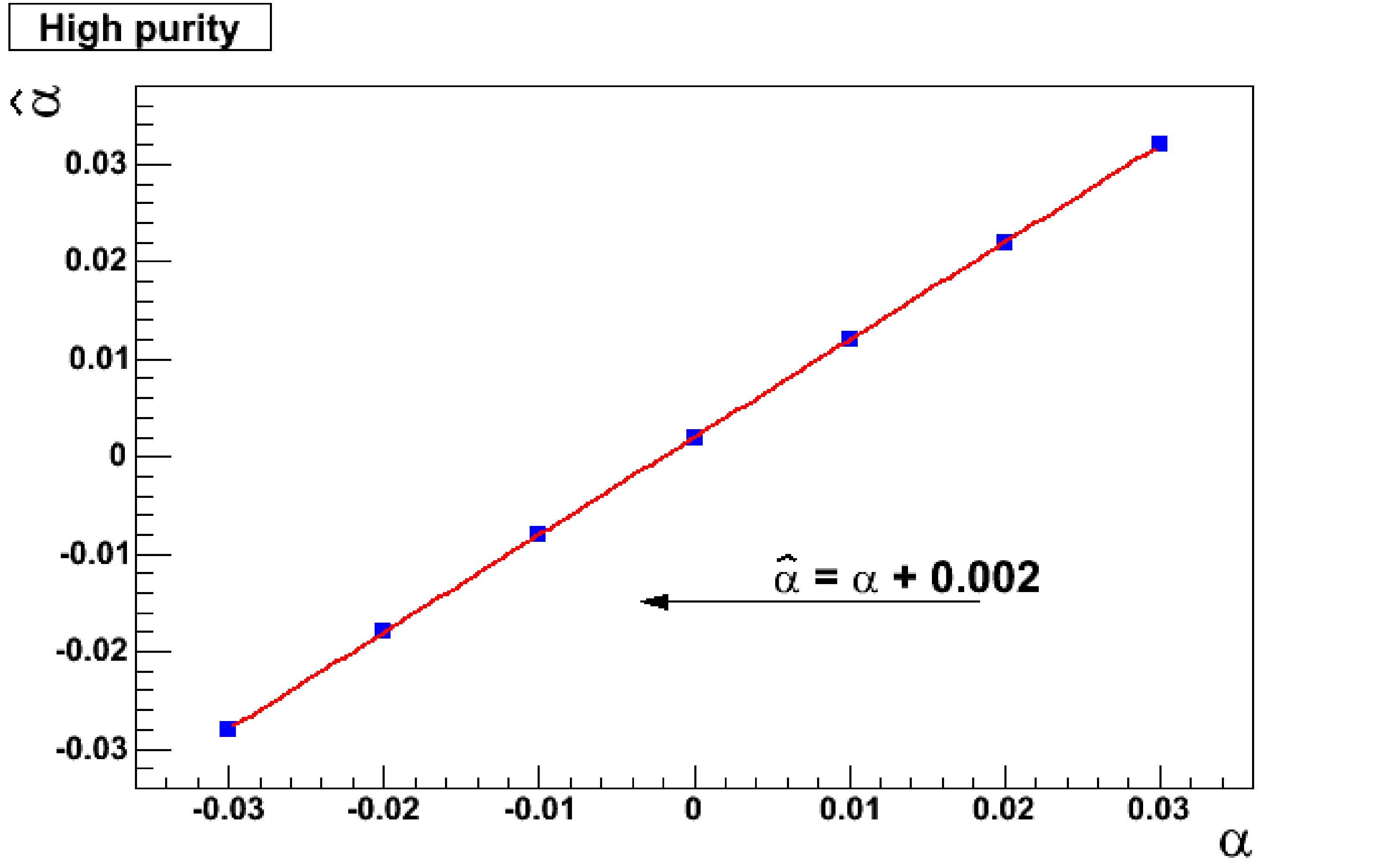
$Q = 22.8 \pm 0.4$ against $Q_{Dashen} = 24.2$

Remember

$$Q^2 \equiv \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$$

$$Q^2{}_{Dashen} = \frac{m_K^2}{m_\pi^2}\frac{m_K^2 - m_\pi^2}{m_{K^0}^2 - m_{K^+}^2 + m_{\pi^+}^2 - m_{\pi^0}^2}$$

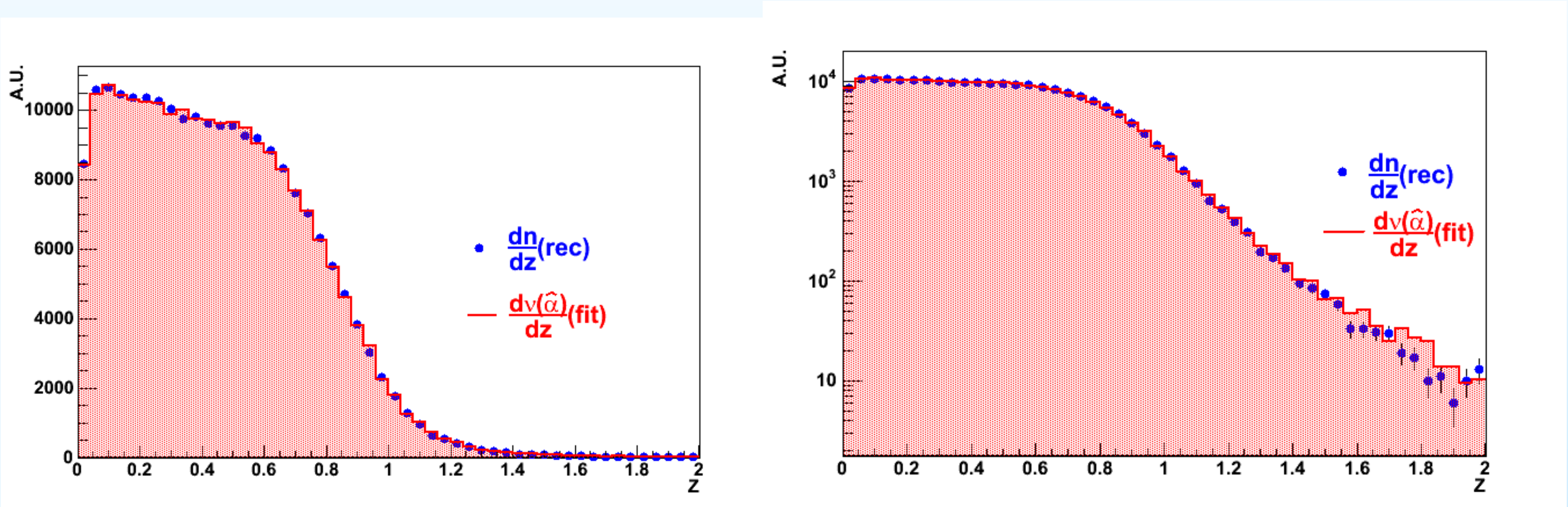
Results on MC



Preliminary result

We have analyzed 350 pb^{-1} of 2001-2002 data and we find the preliminary result, on the high purity sample:

$$\alpha = -0.013 \pm 0.005 \text{ stat } \pm 0.004 \text{ syst}$$

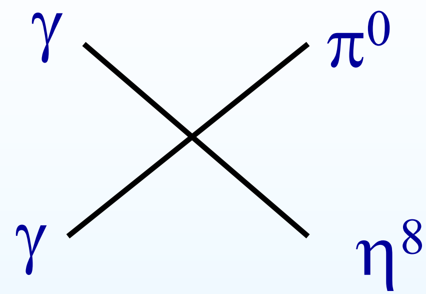


Cfr.current best measurement (Crystal Ball): $\alpha = -0.031 \pm 0.004$ stat+syst

$\eta \rightarrow \pi^0 \gamma\gamma$: a window on p^6 ChPT…

p^2

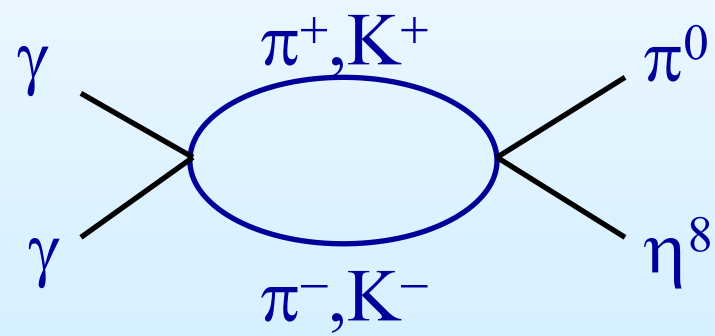
L_2 contributions at tree level:



$= 0 \; (Q = 0)$

p^4

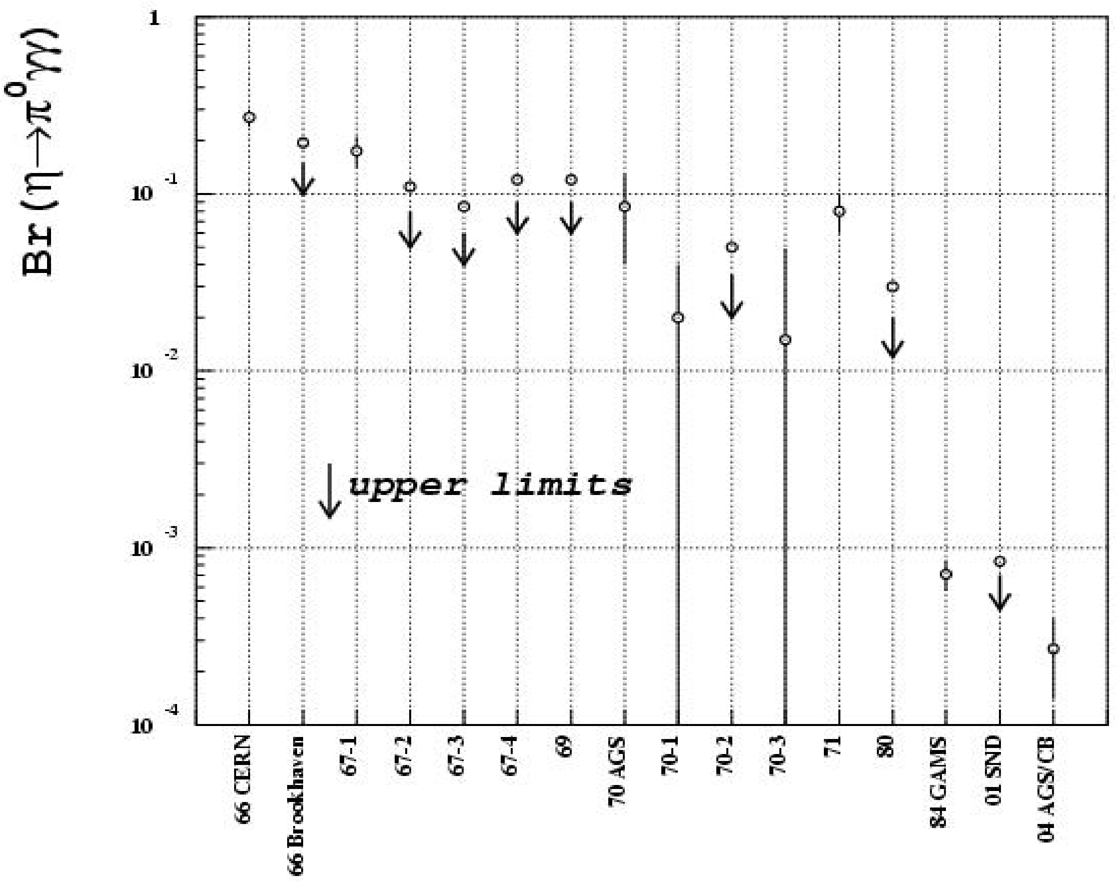
Coupling proportional to the charges, zero also for L_4 @ tree level.
1-loop contributions from L_2 vertices, suppressed by G parity conservation and kaon mass suppression:



Br ~ 3.29×10^{-3} eV/1.18 keV = 2.8×10^{-6}

A window on p^6 physics….

…and an experimental challenge !



$\pi^- + p \rightarrow \eta + n$

(CERN, Brookhaven, GAMS, Crystal Ball)

$\pi^+ + d \rightarrow p + p + \eta$ (67)

$\pi^+ + p \rightarrow \pi^+ + p + \eta$ (67,69)

$K^- + p \rightarrow \Lambda + \eta$ (70 AGS)

$\pi^+ + n \rightarrow \eta + p$ (71)

$\pi^- + n \rightarrow \pi^- + n + \eta$ (80)

$\phi \rightarrow \eta\gamma$ (SND 01)

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

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

└→ $\pi^0\gamma\gamma$

} 5γ final state

σ = 8pb (GAMS Br)

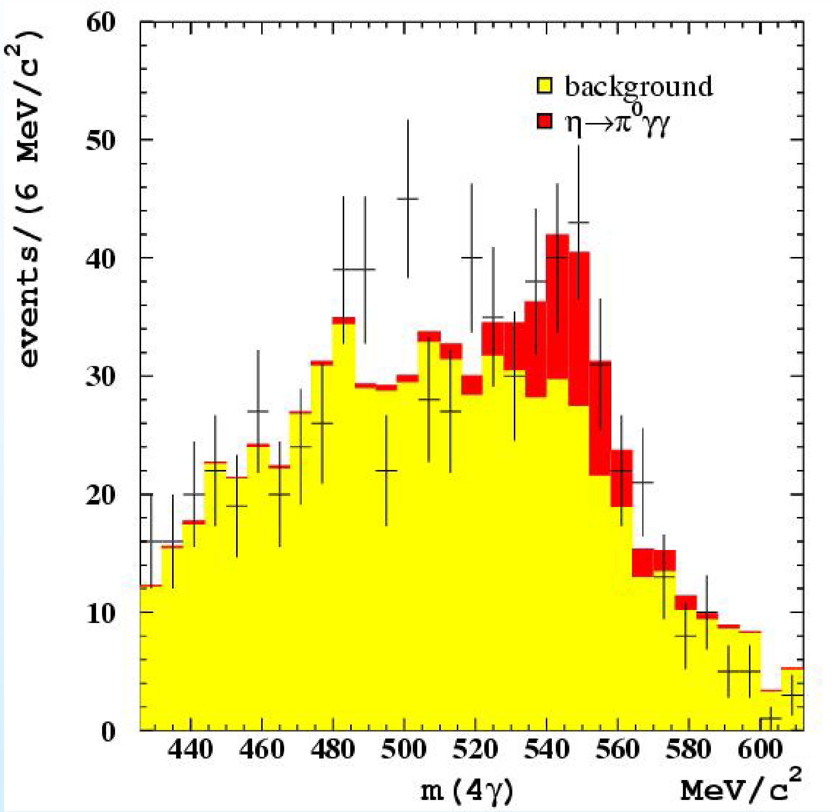
Background candidates:

Channel	σ (pb)
$\omega\pi^0, \omega \to \pi^0\gamma,\ \pi^0 \to \gamma\gamma$	450
$f^0\gamma,\ f_0 \to \pi^0\pi^0,\ \pi^0 \to \gamma\gamma$	300
$a^0\gamma,\ a_0 \to \eta\pi^0,\ \eta \to \gamma\gamma, \pi^0 \to \gamma\gamma$	260
$\eta\gamma, \eta \to \gamma\gamma$	17000
$\eta\gamma,\ \eta \to 3\pi^0$	13000

Reject with veto on additional ω–π^0–η (first three channels)

Reject with energy momentum conservation and likelihood technique to identify merged clusters (last two channels)

Preliminary result



The shape of background + signal after fit well reproduce the data.

$N_{DATA} = 735$

$N_{bkg} = 667 \pm 36$

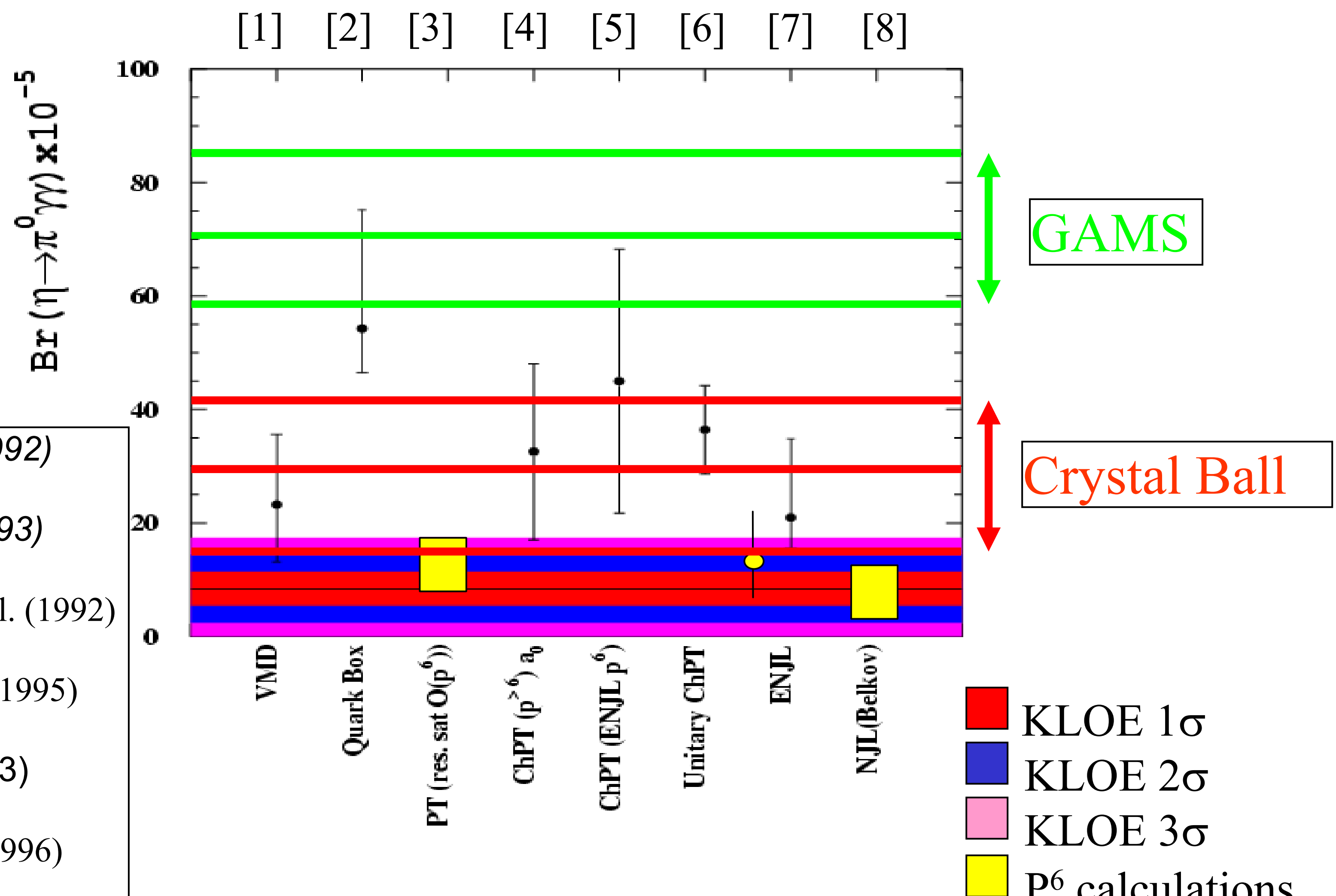
$N_{sig} = 68 \pm 23$

$N(\eta\to 3\pi^0) = 2{,}288{,}882$

$$Br(\eta\to\pi^0\gamma\gamma) = (8.4 \pm 2.7 \pm 1.4) \times 10^{-5}$$

Preliminary

Comparison with models



[1] J. N. *Ng et al.(1992)*

[2] J.N. *Ng et al (1993)*

[3-4] L. Ametller et al. (1992)

[5] S. Bellucci et al. (1995)

[6] E. Oset et al (2003)

[7] J. Bijnens et al. (1996)

[8] A. A. Belkov et al.(1996)

Conclusions

- The f_0 scalar resonance is clearly observed in both $\pi^+\pi^-$ and $\pi^0\pi^0$ final states
- Different models have been used to fit spectra for scalars; we have indication of large values for the coupling of these mesons with ϕ
- In the kaon loop model inclusion af a $\sigma(600)$ broad resonance improves significantly the fit to $\pi^0\pi^0\gamma$ Dalitz plot

Conclusions

- We are analyzing an unprecedented statistics of $\eta\rightarrow3\pi$ decays with negligible background and we have new and accurate values for the Dalitz plot slopes of both $\pi^+\pi^-\pi^0$ and $3\,\pi^0$ final states. These data may point towards a value of $(m_d - m_u)$ larger than the one usually found in literature.

- We measure a value of BR($\eta\rightarrow\pi^0\gamma\gamma$) smaller by factor 3 wrt recent Crystal Ball value (and an order of magnitude smaller than PDG value) still significantly different from zero, and in agreement with ChPT p^6 calculations.