Status of $\phi \to \eta'\gamma$ analysis

F. Ambrosino
Università e Sezione INFN Napoli

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Motivations

- The value of the ϑ_P mixing angle has been a puzzle for many years. Both theoretical predictions and phenomenological analyses in literature vary as much as $-23^\circ \rightarrow -10^\circ$.

- Recently a deeper theoretical insight suggests the need to use two mixing parameters ϑ_8 and ϑ_0 in the octet-singlet basis.

- One can show that at NLO in EχPT $\vartheta_0 - \vartheta_8 \simeq 16^\circ$: hence the approximation $\vartheta_8 = \vartheta_0 = \vartheta_P$ is not reliable.

- In the flavor basis, instead, the two mixing parameters ϕ_q and ϕ_s are equal (apart from OZI rule violation effects).

- The value of $\phi_q \simeq \phi_s = \varphi_P$ can be extracted from the ratio of the amplitudes of $\phi \rightarrow \eta'\gamma$ and $\phi \rightarrow \eta\gamma$.

- The angle φ_P can then be related to ϑ_8, ϑ_0 through the decay constants f_q, f_s.

The first channel we are studying is:

$\phi \to \eta' \gamma \ \to \pi^+ \pi^- \eta \gamma \to \pi^+ \pi^- \gamma\gamma\gamma$ (BR $\approx 10^{-5}$)

Main Backgrounds:

- $\phi \to K_S K_L$; (K_L decaying before DC and splitting/accidentals)
- $\phi \to \pi^+ \pi^- \pi^0$; (splitting/accidentals)
- $\phi \to \eta\gamma \ \to \pi^+ \pi^- \pi^0 \gamma \to \pi^+ \pi^- \gamma\gamma\gamma$ (BR $\approx 2.9 \times 10^{-3}$)

$\phi \to \eta\gamma \to \pi^+ \pi^- \gamma \gamma \gamma$ can be selected with very small background ($< 1\%$) and is thus a useful control sample.

The analysis for 1999 data was a two-step procedure; essentially:

- Topological selection
- Kinematic fit with all mass constraints and cut on χ^2 probabilities.

Results where presented at Osaka ICHEP 2000

$$\frac{BR(\phi \to \eta'\gamma\ )}{BR(\phi \to \eta\gamma\ )} = (7.1 \pm 1.6(\mathrm{stat.}) \pm 0.3(\mathrm{syst.})) \times 10^{-3}$$

An advantage of this approach was the very high S/B useful to extract the signal from a low statistics channel. A disadvantage was the difficulty on the evaluation of the systematic effect on the efficiencies coming from the Prob(χ^2) cuts.

In 2000 we have collected a statistics ~ 10 times larger, so we can achieve a factor 3 on statistical error, comparable to the systematics we had for 1999. Moreover events are much less clean than in the past. This suggests a different approach to 2000 data, wich make no use of kinematic fits with mass constraints.

$\pi^+\pi^-\gamma\gamma\gamma$ *common selection*

First level: topological as in 1999 data analysis. Same cuts applied for $\phi \to \eta'\gamma$ and $\phi \to \eta\gamma$ selection:

- 1 charged vertex in cylindrical region around IP ($\rho < 4\mathrm{cm};\ |z| < 8\mathrm{cm}$)
- 3 photons with $|t - l/c| < 5\sigma_t$
- max$(\cos(\theta_{\gamma\gamma})) < 0.95$ (New, to reduce background due to cluster splitting.)

Second level : as in 1999 data analysis, loose cuts on charged pions energy endpoints to reduce $K_L K_S$ and $\pi^+\pi^-\pi^0$ backgrounds:

- $E_{\pi^+} + E_{\pi^-} < 430$ MeV for $\phi \to \eta'\gamma$
- $E_{\pi^+} + E_{\pi^-} < 550$ MeV for $\phi \to \eta\gamma$

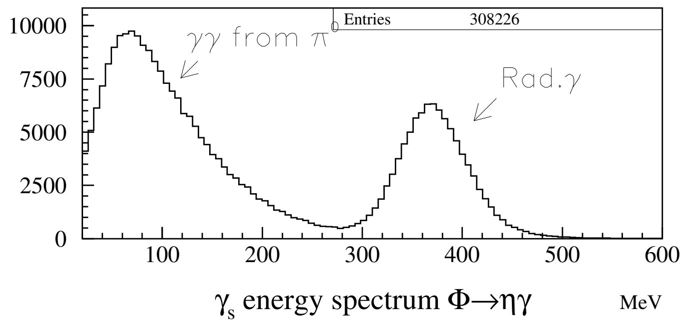
A kinematic fit with no mass constraints is then applied in order to improve resolutions (mainly photons energy resolutions). A cut on $\mathcal{P}(\chi^2) > 1\%$ ensures energy-momentum conservation for the event.

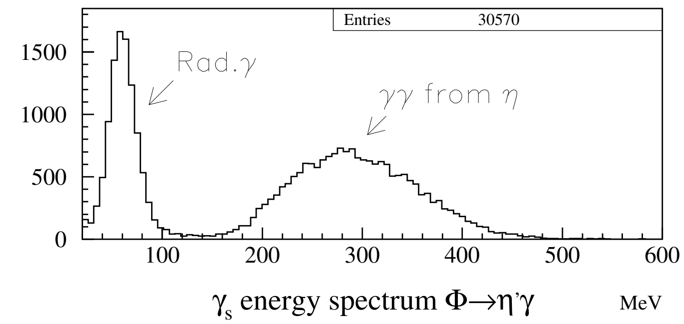
Monte Carlo efficiencies for both $\phi \to \eta\gamma$ and $\phi \to \eta'\gamma$ events have been studied in detail, including correlation among trigger efficiency, FILFO and EVCL efficiencies and radiative selection. The main results are:

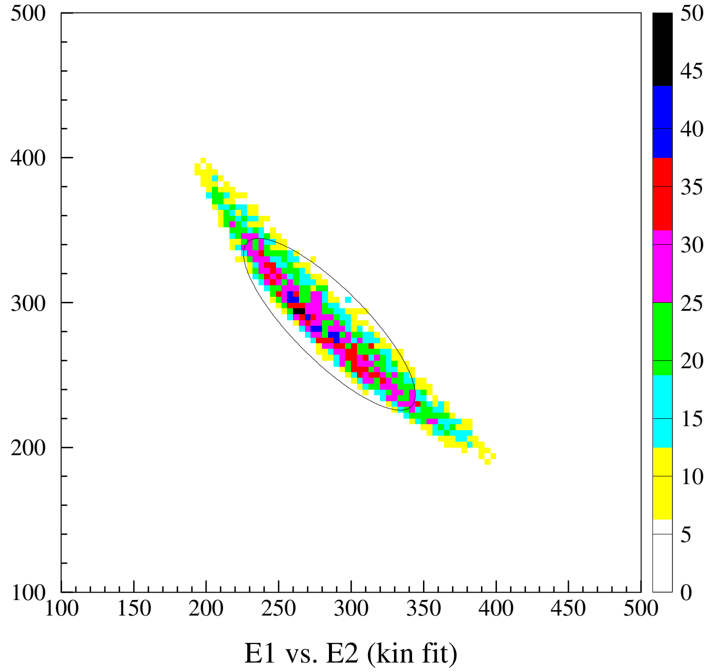
- The topological efficiency $\epsilon = \epsilon_{TRIG} \cdot \epsilon_{FILFO} \cdot \epsilon_{EVCL} \cdot \epsilon_{RADSEL}$ is by far dominated by event classification and radiative selection: $\epsilon \simeq \epsilon_{EVCL} \cdot \epsilon_{RADSEL}$
- The ratio $\frac{\epsilon_{\eta'\gamma}}{\epsilon_{\eta\gamma}}$ is relatively close to unity (0.923) and pretty stable. Even shifting the time of each photon by $+200$ ps the ratio goes to 0.924 (while individual efficiencies change by $\pm 2 - 3\%$. Similar checks have been performed varying the photon energy (miscalibration by $\pm 2\%$) and the cut on ϑ_γ $(\pm 2^\circ)$.

η' selection

The photon spectrum of $\phi \rightarrow \eta'\gamma$ and $\phi \rightarrow \eta\gamma$ events allows a very clear identification of the photons in the two cases:

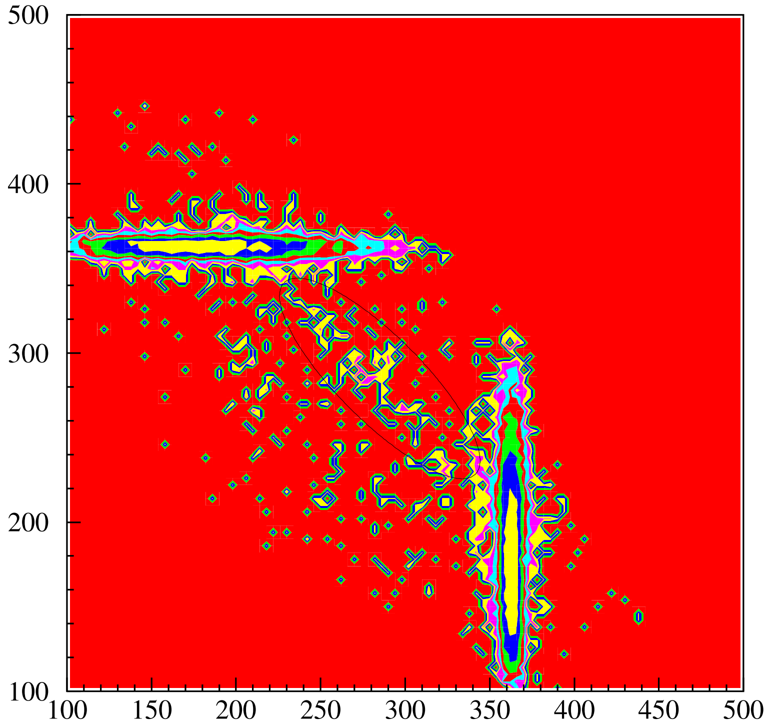






This can be used to exploit correlation between the two hardest photons energies in $\phi \rightarrow \eta'\gamma$ events.

A cut in the plane E1 versus E2 has a good rejection power on $\phi \rightarrow \eta\gamma$ events. After the previous selection about 35% of $\phi \rightarrow \eta\gamma$ events where still selected. After this cut this number is at level 10^{-4}. The energy of the hardest photon can also be used to select the $\phi \rightarrow \eta\gamma$ events.



E1 vs E2 (fit no m.c.)

The $\phi \rightarrow \eta\gamma$ events can be selected simply with a loose cut on the bands in the plane E1 vs E2. The cut is set at $320 < E_\gamma < 400$ MeV $(= \pm 10\sigma)$.

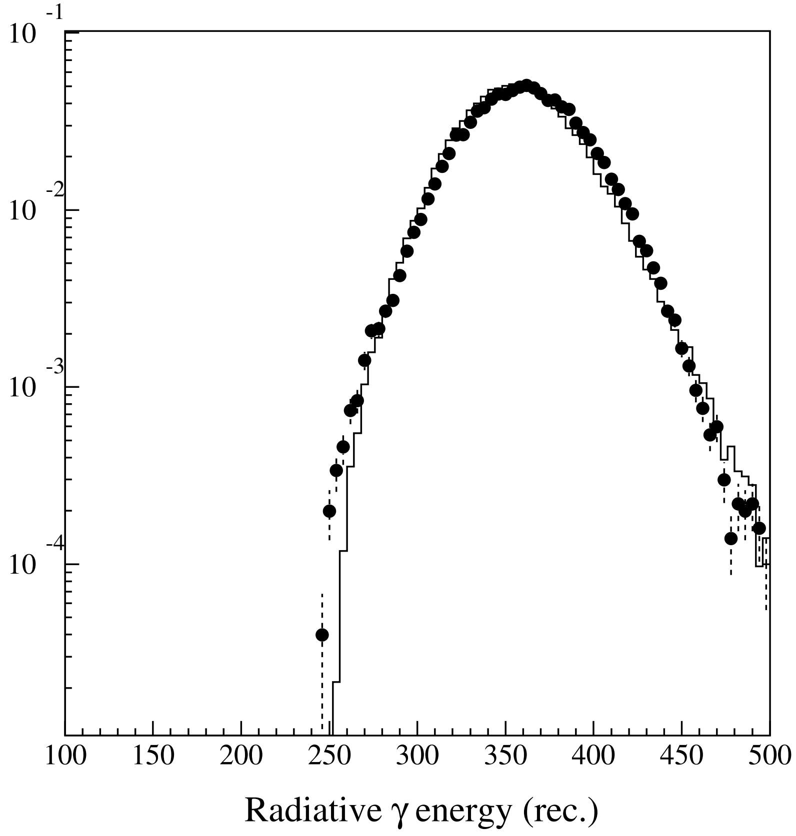
All kinematical quantities relevant for selection can be checked in the $\phi \rightarrow \eta\gamma$ sample to find discrepancies with Monte Carlo (see plots).

Almost all variables are in very good agreement with Monte Carlo. Systematics effects on efficiencies evaluated with Monte Carlo are very small.

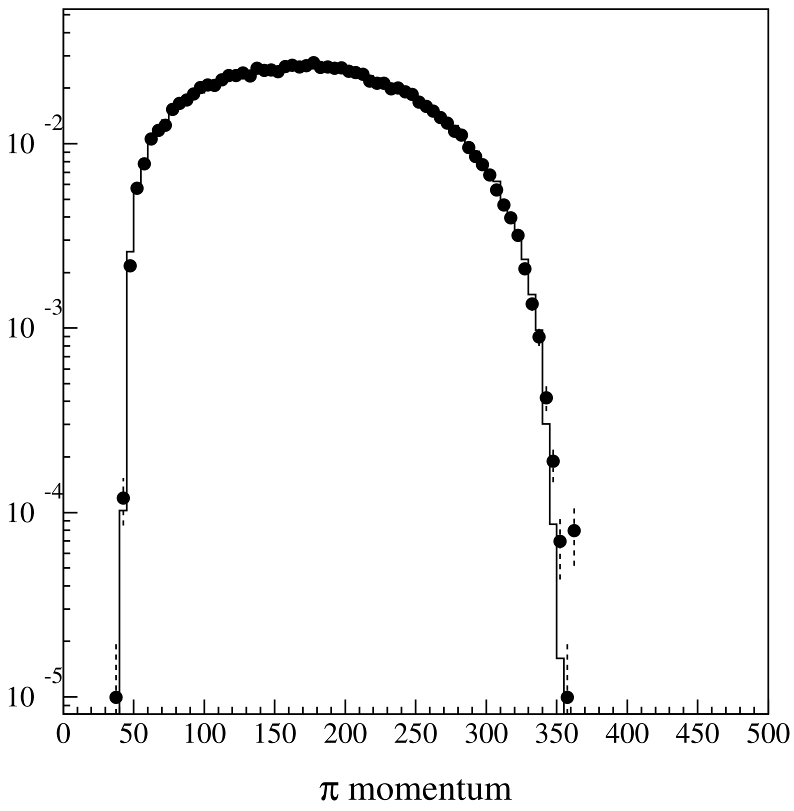
Also the pulls of the kinematic fit exhibit a nicely regular behavior, with exception for the photons time of flight pulls (see plots).

The χ^2 probability is slightly different between data and MC, however the values of this probability is in nice agreement on data between $\phi \rightarrow \eta\gamma$ and $\phi \rightarrow \eta'\gamma$ events.

The η control sample

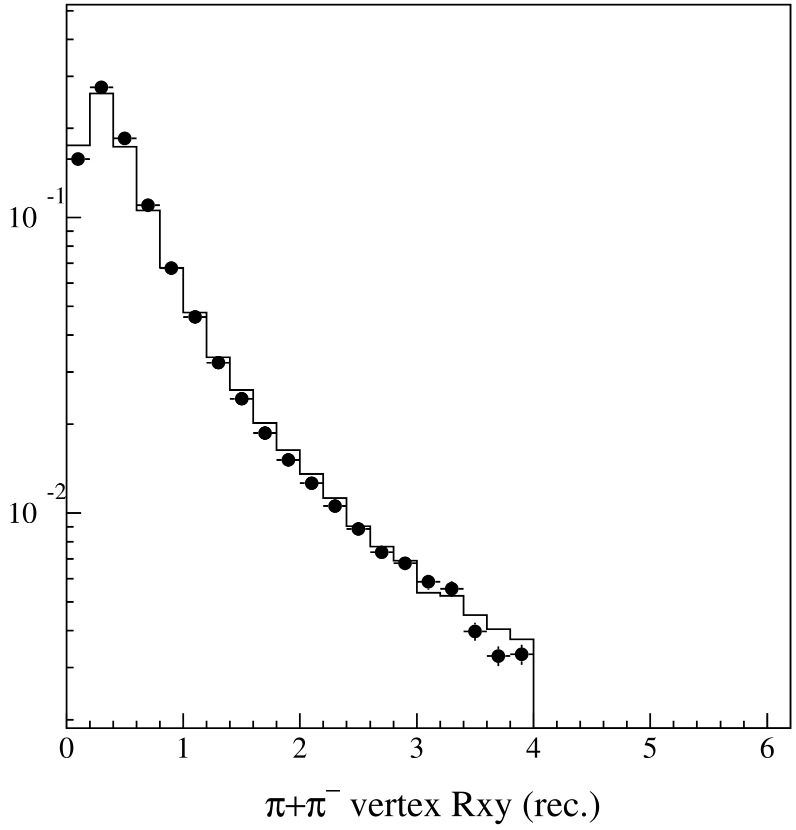


Rad. γ energy

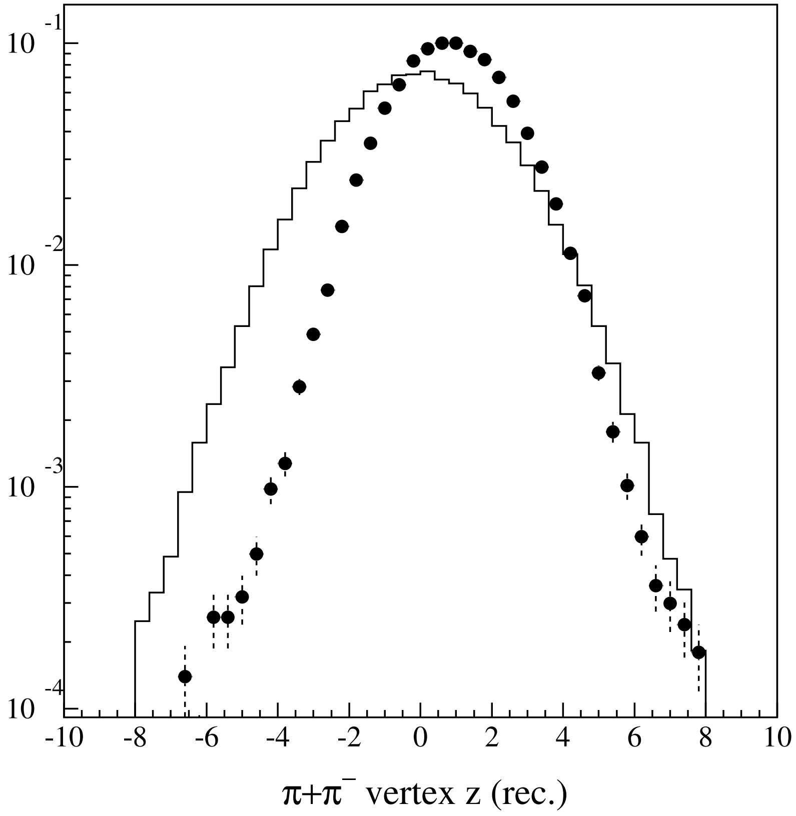


Pion momentum

The η control sample

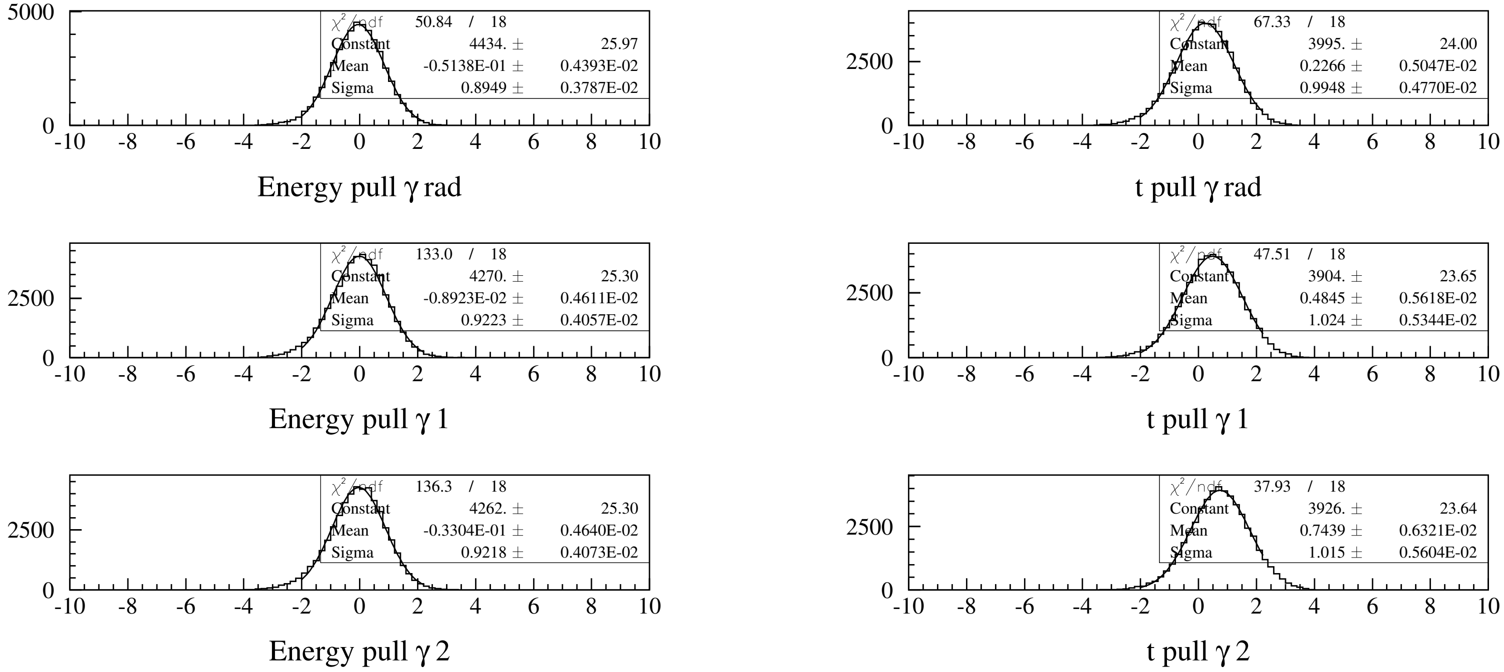


Charged vertex ρ



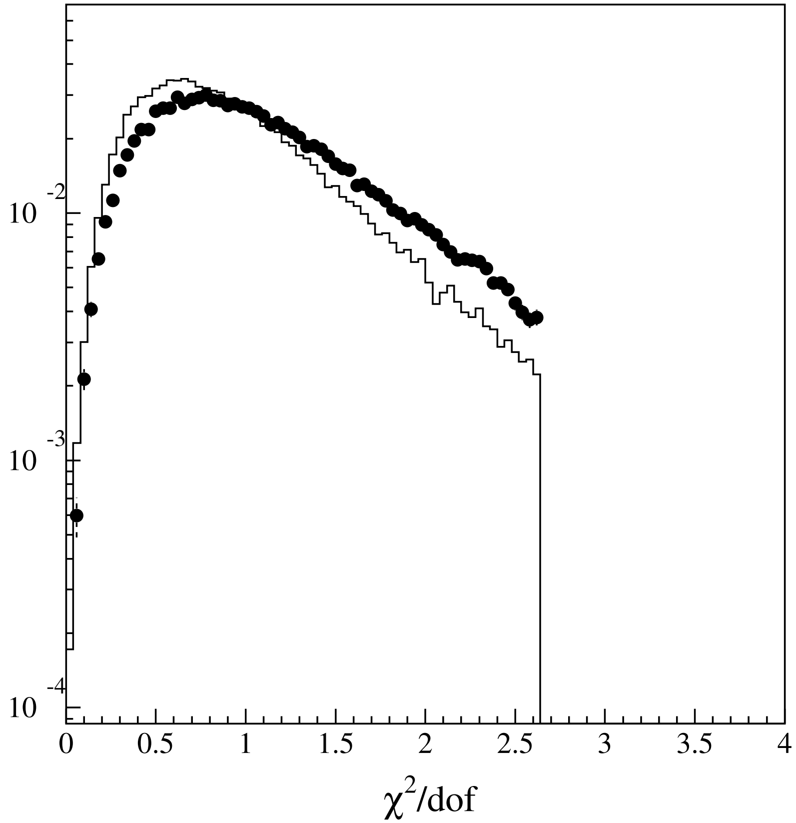
Charged vertex z

The η control sample

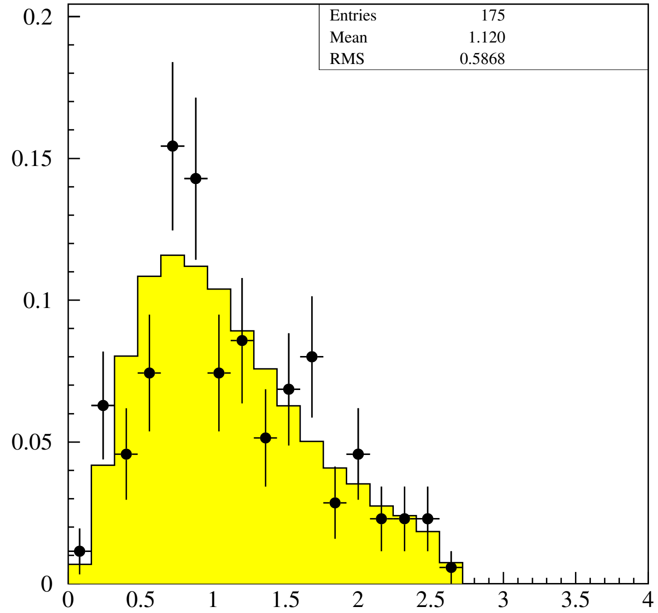


Kin. fit: energy pulls (DATA)

Kin. fit: time pulls (DATA)



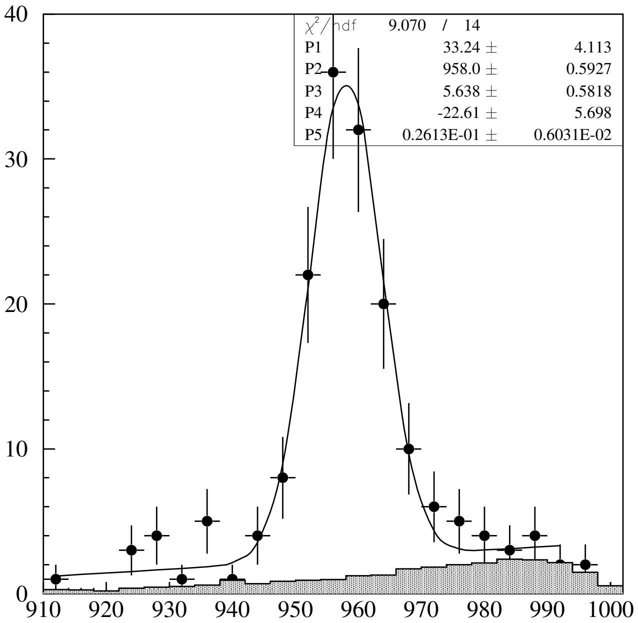
Kin. fit χ^2/dof(DATA-MC)



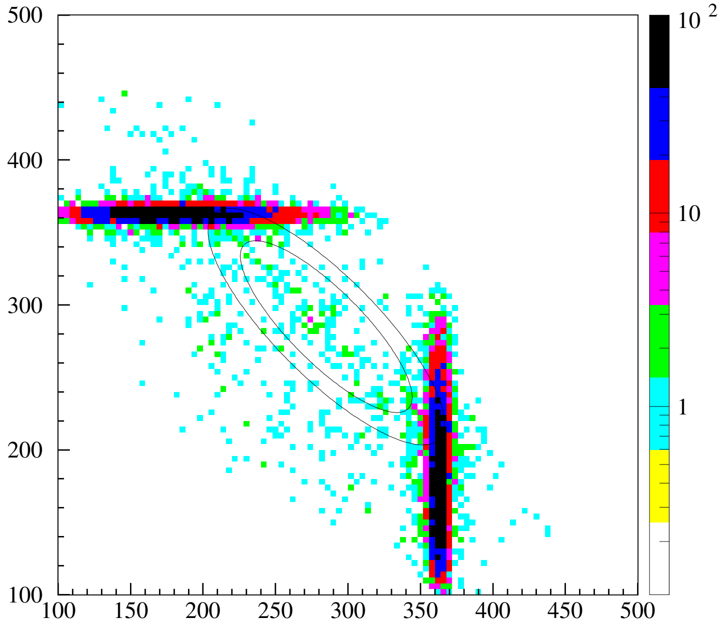
Kin. fit χ^2/dof $(\eta - \eta')$

The η' peak

Since there is no mass constraint in the kinematic fit, one can look directly at distributions of kinematical quantities on data to evaluate background and subtract it. This has been done on the η' invariant mass peak.



Etaprime inv. mass (fit no m. c.)



E1 vs. E2 (kin fit)

The parameters of the gaussian fit are almost the same of the result of the fit to the η' mass on Monte Carlo. Also all other kinematical quantities are well in agreement with expectations.

Systematics

- $\pm 4\%$ from background subtraction
- $\pm 5\%$ from intermediate BR
- $\pm 5\%$ on $\frac{\epsilon_\eta}{\epsilon_{\eta'}}$

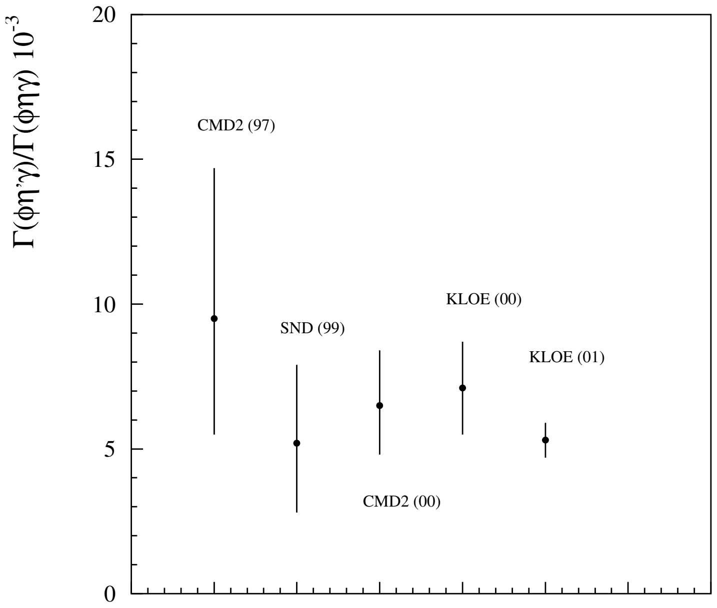
Systematics on efficiency ratio has been evaluated as follows:

- Take the central values for integrated luminosity and σ_ϕ
- Take BR($\phi \to \eta\gamma$) and intermediate BR's from PDG.
- Evaluate the expected number of $\phi \to \eta\gamma \to \pi^+ \pi^- \gamma \gamma \gamma$ events.
- Evaluate "a posteriori" efficiency on DATA (possible because of small background)
- Compare with Monte Carlo efficiency. Strong dependence from $\mathcal{P}(\chi^2)$ cut (as expected).
- Cutting over a large range on $\mathcal{P}(\chi^2)$ does not affect significantly the ratio R.
- When on "saturation" residual discrepancy is $\frac{|\epsilon_{MC} - \epsilon_{DATA}|}{\epsilon_{MC}} = 5\%$. Take this value as relative error on the efficiency ratio.

The ratio $BR(\phi \to \eta'\gamma)/BR(\phi \to \eta\gamma)$

With the current choice of the cuts we find $N_{\eta'} = 124 \pm 12(\text{stat.}) \pm 5(\text{syst.})$. And thus, for the ratio:

$$\boxed{R = \frac{BR(\phi\to\eta'\gamma)}{BR(\phi\to\eta\gamma)} = \frac{N_{\eta'}}{N_\eta}\frac{\epsilon_\eta}{\epsilon_{\eta'}} R_{BR} = (5.3 \pm 0.5(\text{stat.}) \pm 0.4(\text{syst.})) \cdot 10^{-3}}$$



The mixing angle(s)

We have considered both the approaches in *Bramon et al. (Eur. Phys J. C7 (99)* and the one in *T. Feldmann (Int. J. Mod. Phys A15 (00))* to extract the mixing angle φ_P in the flavor basis.

We find the same result with the two methods:

$$\boxed{\varphi_P = (40^{+1.7}_{-1.5})^\circ}$$

Translated into the old-fashioned ϑ_P language, this would imply $\vartheta_P = (-14.7^{+1.7}_{-1.5})^\circ$.

Using instead the values $f_s = 1.34 \cdot f_\pi$; $f_q = 1.07 \cdot f_\pi$; one can then extract the mixing angles in the octet-singlet basis:

$$\boxed{\vartheta_8 \simeq -20.5^\circ; \qquad \vartheta_0 \simeq -8.5^\circ}$$

Conclusions

- Using 16.6 pb^{-1} of year 2000 data has been possible to extract the ratio $\Gamma(\phi \rightarrow \eta'\gamma)/\Gamma(\phi \rightarrow \eta\gamma)$ and hence the mixing parameters of the $\eta - \eta'$ system with an error which is significantly smaller than the one obtained with 1999 data (which was at level of the world average) in the $\pi^+\pi^-\gamma\gamma\gamma$ final state.
- Further developments on this channel may include:

1. use of improved cluster reconstruction to reduce splitting
2. use of time slewing corrections in kinematic fit to have better matching DATA-MC.
3. Understanding of residual efficiency effects on $\phi \rightarrow \eta\gamma$

- The analysis of $\pi^+\pi^- 7\gamma$ final state is proceeding. First checks on the number of selected events show agreement with the $\pi^+\pi^-\gamma\gamma\gamma$ results.
- Future plans:
  complete the $\pi^+\pi^- 7\gamma$ analysis and merge the results for BR($\phi \rightarrow \eta'\gamma$)