

# **KLOE first results on hadronic physics**



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# Outline



- First DAΦNE run for KLOE : end of 1999

- ⇒  $\int L dt = 2.4 \text{ pb}^{-1}$  collected

- ⇒  $\sim 7.7 \times 10^6$   $\phi$  produced

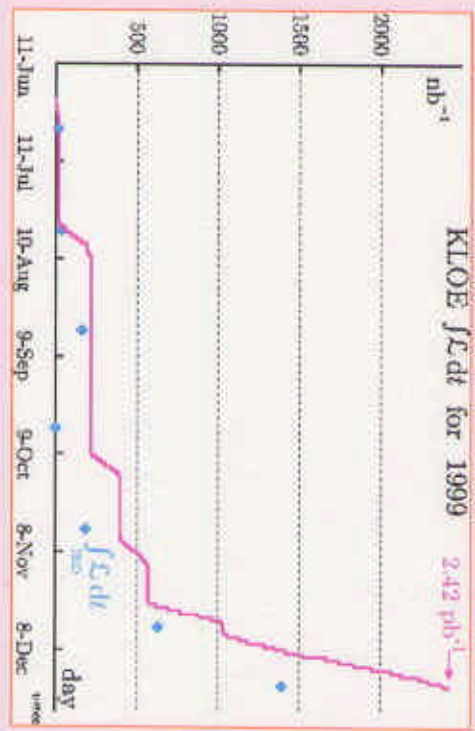
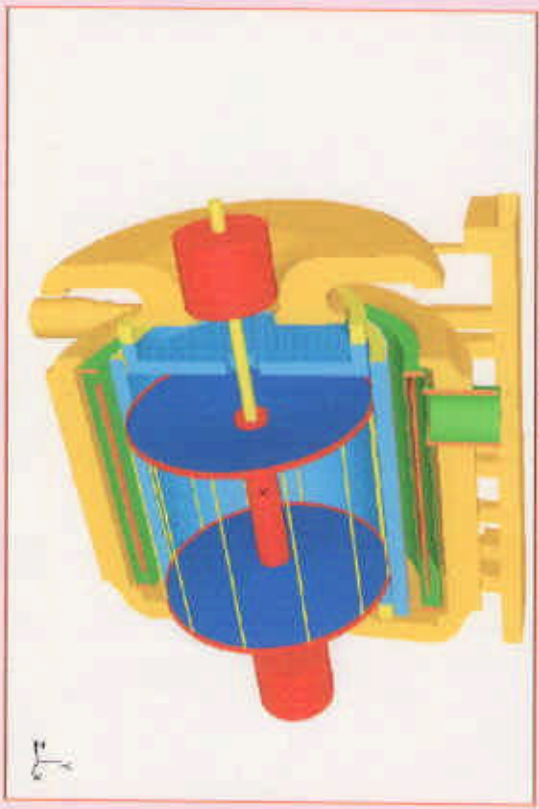
- Hadronic physics at KLOE:

- Radiative decays of  $\phi$ :

- $\phi \rightarrow f_0 \gamma, a_0 \gamma$

- $\phi \rightarrow \eta \gamma, \eta' \gamma$

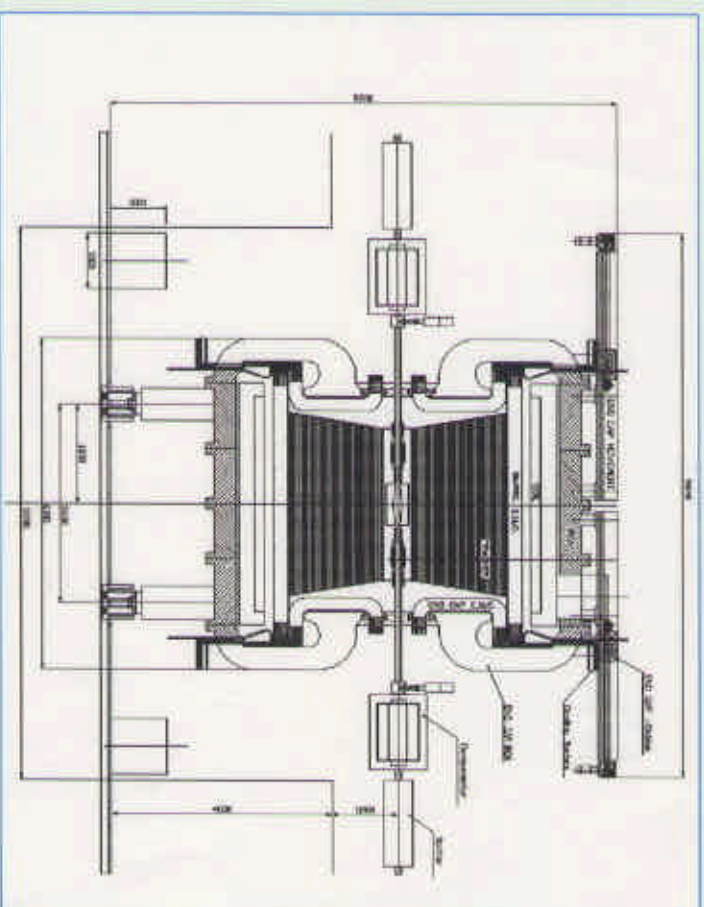
- $\phi \rightarrow \pi^+ \pi^- \pi^0$



# KLOE



- E.m.calorimeter: Pb/SciFi fine sampling  
Hermetic, with high efficiency for low energy photons  
 $\sigma_{E/E} = 6\%/\sqrt{|E|[\text{GeV}]}$   
 $\sigma_t = 54 \text{ ps}/\sqrt{|E|[\text{GeV}]} \oplus 147 \text{ ps}$
- Drift chamber with  
He based gas mixture  
 $\sigma_{\text{vert}} \sim 1\text{mm}$ ;  $\sigma_{p_t/p_t} \sim 0.5\%$   
 $\sigma_{r_{\text{FP}}} \sim 200 \mu\text{m}$
- Quadrupoles' calorimeters:  
Pb/Sci tile
- Superconducting magnet  $B=0.56 \text{ T}$





$$\phi \rightarrow f_0 \gamma, a_0 \gamma$$

- $f_0(980)$   $1G(J^{PC}) = 0^+ (0^{++})$   $\Gamma \approx 50 \text{ MeV}$   
 $a_0(980)$   $1G(J^{PC}) = 1^- (0^{++})$  ' '
- The nature of these scalars is not clear:  $q\bar{q}$ ,  $q\bar{q}q\bar{q}$  states,  $K\bar{K}$  molecule?
- The  $\text{Br}(\phi \rightarrow f_0 \gamma, a_0 \gamma)$  are sensitive to their structure

Model for $f_0$	$\text{BR}(\phi \rightarrow f_0 \gamma)$
$(q\bar{q})_{I=0}$	$\sim 10^{-6}$
$(s\bar{s})_{I=0}$	$\sim 10^{-5}$
$(\bar{q}q\bar{q}\bar{q})_{I=0}$	$\sim 10^{-4}$
$(K\bar{K})_{I=0}$	$\sim 4 \times 10^{-5}$
$(g\bar{g})_{I=0}$	$< 10^{-6}$

Measurements from VEPP-2M  
 experiments CMD-2 and SND:

$$\text{Br} \approx 10^{-4}$$

(M.N.Achasov et al., Phys.Lett.B479(2000)53

M.N.Achasov et al., hep-ex/0005017

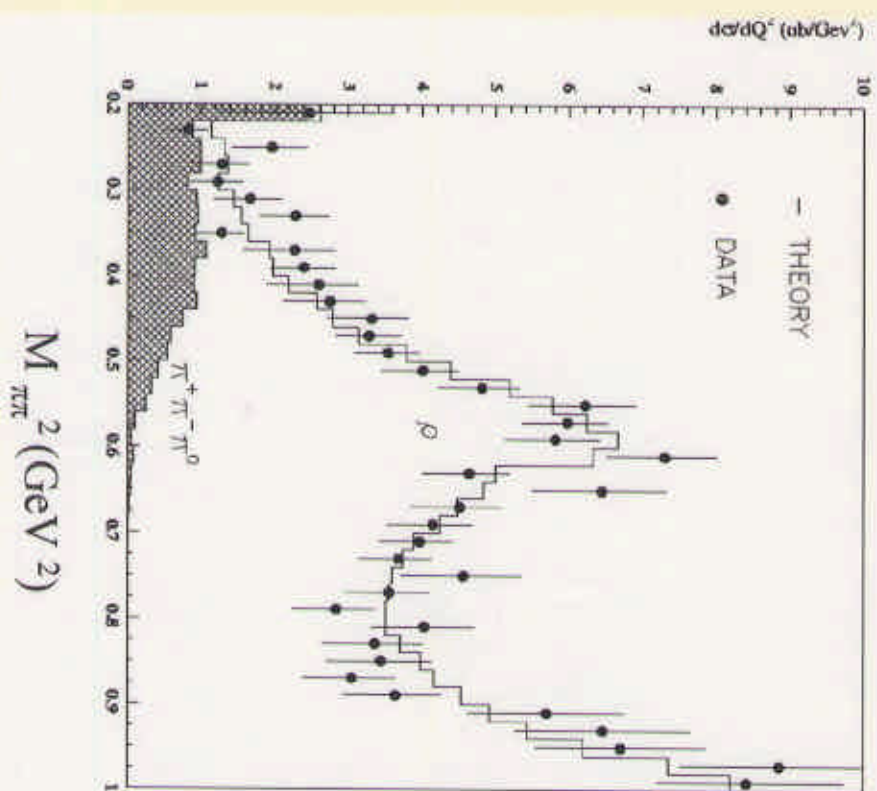
R.R.Akmetshin et al., Phys.Lett.B462(1999)371

R.R.Akmetshin et al., Phys.Lett.B462(1999)380)

## $\phi \rightarrow f_0 \gamma$ (charged final state)



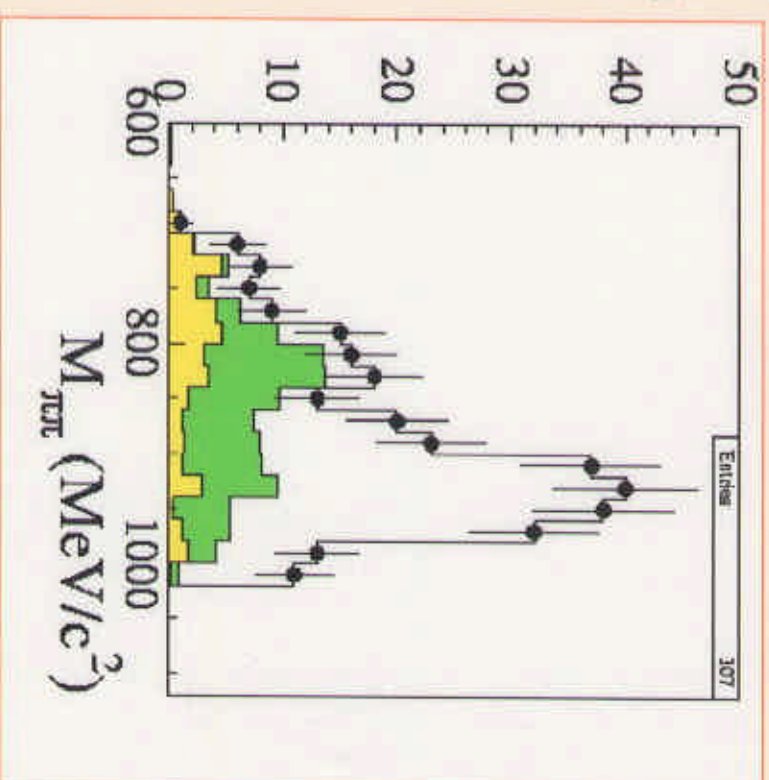
- $\phi \rightarrow f_0 \gamma \rightarrow \pi^+ \pi^- \gamma$
  - $e^+ e^- \rightarrow \gamma^* \rightarrow \pi^+ \pi^- \gamma$  FSR
  - $e^+ e^- \rightarrow \gamma \gamma^* \rightarrow \pi^+ \pi^- \gamma$  ISR
  - Analyzed sample = 1.8 pb<sup>-1</sup>
  - $\epsilon \approx 50\%$
  - Fit the  $M_{\pi\pi}^2$  distribution to theoretical spectrum up to 0.84 GeV<sup>2</sup> – extrapolate to the signal region:
- No evidence for  $f_0$  signal**
- $\Rightarrow \text{Br}(\phi \rightarrow f_0 \gamma \rightarrow \pi^+ \pi^- \gamma) < 1.6 \times 10^{-4}$  @ 90% C.L.





## $\varphi \rightarrow f_0 \gamma$ (neutral final state)

- $\varphi \rightarrow f_0 \gamma \rightarrow \pi^0 \pi^0 \gamma$       **Br  $\approx 10^{-4}$**
- $e^+ e^- \rightarrow \omega \pi^0 \rightarrow \pi^0 \pi^0 \gamma$       **S/B  $\approx 0.5$**
- $\varphi \rightarrow \rho \pi^0 \rightarrow \pi^0 \pi^0 \gamma$        $\approx 3$
- $\varphi \rightarrow a_0 \gamma \rightarrow \eta \pi^0 \gamma \rightarrow 5 \gamma$        $\approx 3$
- **Analyzed sample = 1.8 pb $^{-1}$**
- **$\epsilon = 40\%$**
- **$N_{\text{obs}} = 307 \pm 18$  events**
- **$N_{\text{bcgk}} = 112 \pm 11$**
- **$\text{Br}(\varphi \rightarrow f_0 \gamma \rightarrow \pi^0 \pi^0 \gamma) = (0.81 \pm 0.09 \pm 0.06) \times 10^{-4}$**

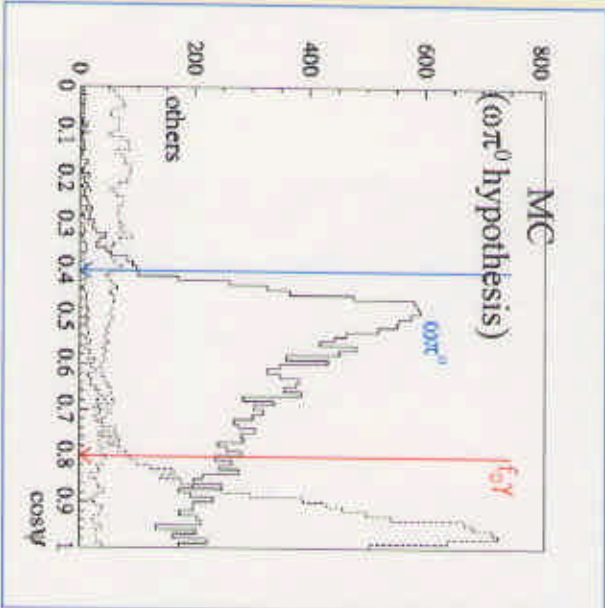




$\psi$  = angle between  $\gamma$  and  $\pi^0$

in the dipion rest frame

$0.4 < \cos\psi < 0.8$

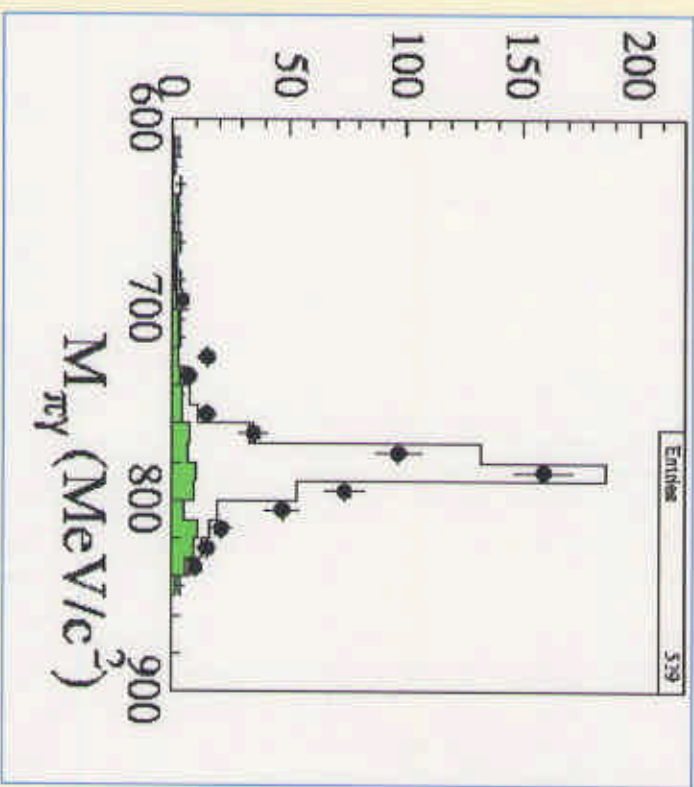


•  $\epsilon = 35\%$

$N_{obs} = 529 \pm 23$  events

$N_{bcgk} = 93 \pm 10$

$\sigma(e^+e^- \rightarrow \omega \pi^0) = (0.67 \pm 0.04 \pm 0.05) \text{ nb}$





## $\phi \rightarrow a_0 \gamma$ (neutral final state)

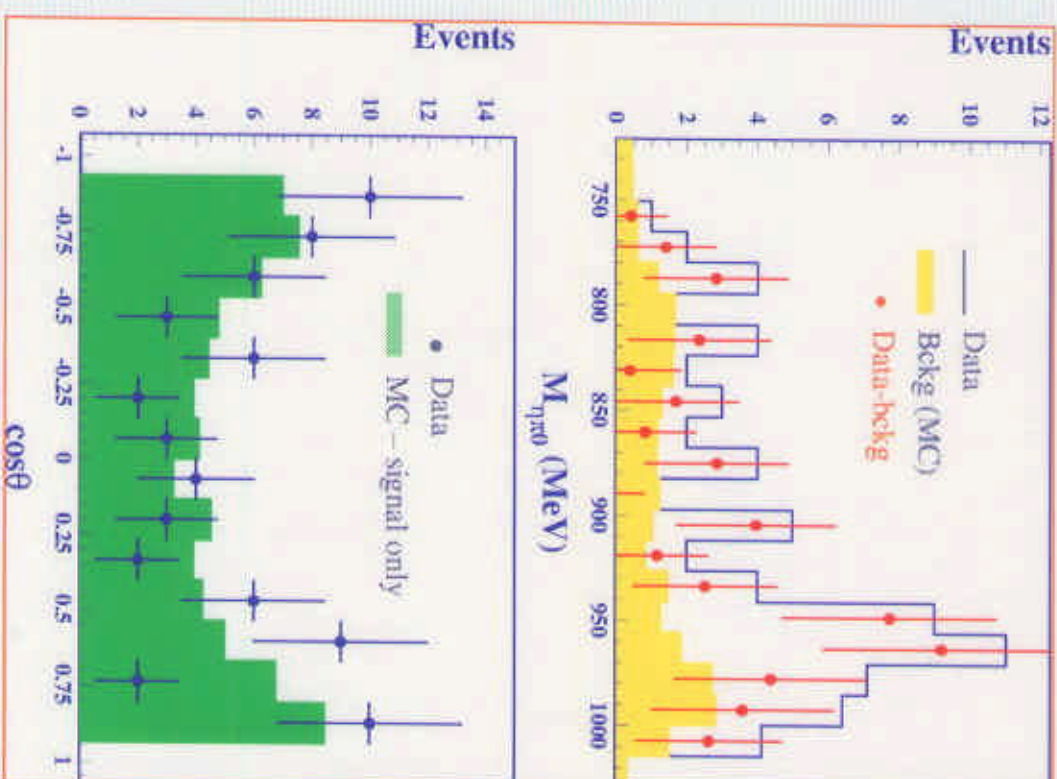
- $\phi \rightarrow a_0 \gamma \rightarrow \eta \pi^0 \gamma \rightarrow 5 \gamma$  ( $\eta \rightarrow \gamma \gamma$ )  $\text{Br} \approx 3.5 \times 10^{-5}$
- $\phi \rightarrow \rho \pi^0 \rightarrow \eta \pi^0 \gamma$   $\text{S/B} \approx 7$
- $e^+ e^- \rightarrow \omega \pi^0 \rightarrow \eta \pi^0 \gamma$   $\approx 20$
- $\phi \rightarrow \pi^0 \pi^0 \gamma$   $\approx 0.1$
- Analyzed sample =  $2.4 \text{ pb}^{-1}$
- $\epsilon = 23\%$

$N_{\text{obs}} = 74 \pm 9$  events

$N_{\text{bckg}} = 21 \pm 6$

$\text{Br}(\phi \rightarrow \eta \pi^0 \gamma) = (0.77 \pm 0.15 \pm 0.10)$

$\times 10^{-4}$







$\varphi \rightarrow \eta \gamma, \eta' \gamma$

- $\text{Br}(\varphi \rightarrow \eta' \gamma)$  is sensitive to the gluonic contents of  $\eta'$   
Theoretical predictions range from  $10^{-4}$  to  $10^{-6}$  (large gluonic contents)
- Measurements from VEPP-2M  $\sim (7 \div 8) \times 10^{-5}$
- $\eta - \eta'$  mixing angle ( $\vartheta_P$ ) from the ratio:

$$R_\phi = \frac{\text{BR}(\phi \rightarrow \eta' \gamma)}{\text{BR}(\phi \rightarrow \eta \gamma)} = \cot^2 \varphi_P \left( 1 - \frac{m_s \tan \varphi_V}{\bar{m} \sin 2\varphi_P} \right)^2 \left( \frac{p_{\eta'}}{p_\eta} \right)^3$$

with  $\varphi_P = \vartheta_P + \arctan \sqrt{2}$

(see A. Bramon et al., Eur Phys. J C7 (1999))

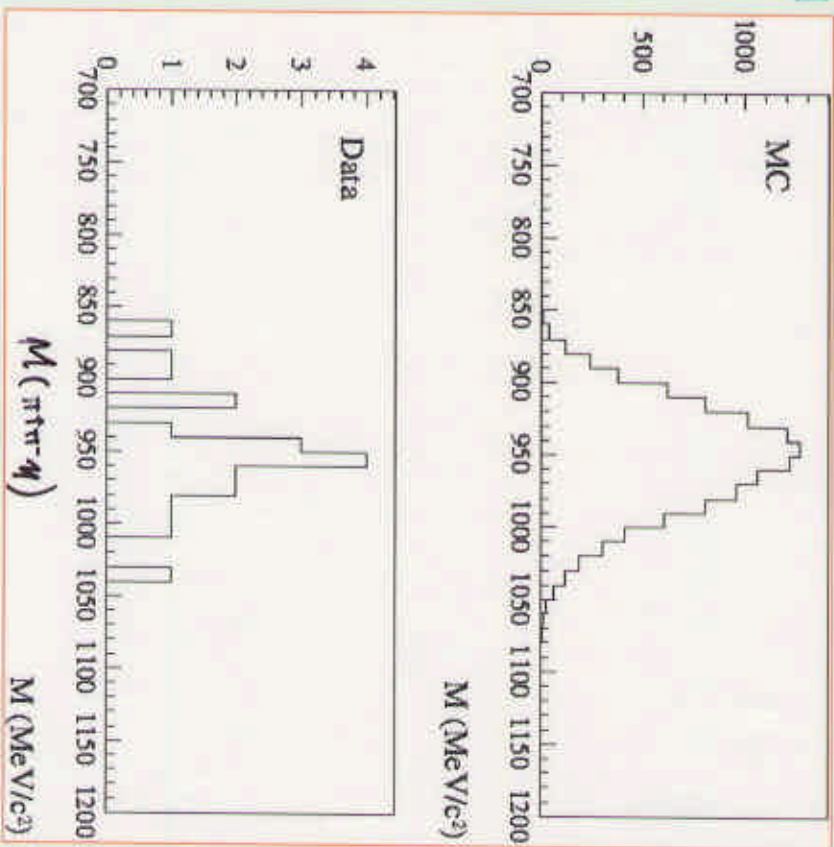
Theoretical predictions:  $\vartheta_P \approx -10^\circ$  (Gell Mann – Okubo)  
 $-20^\circ$  (Chiral calculations)

Experimental data:  $-13^\circ \div -20^\circ$

## $\phi \rightarrow \eta \gamma, \eta' \gamma$ (charged final state)



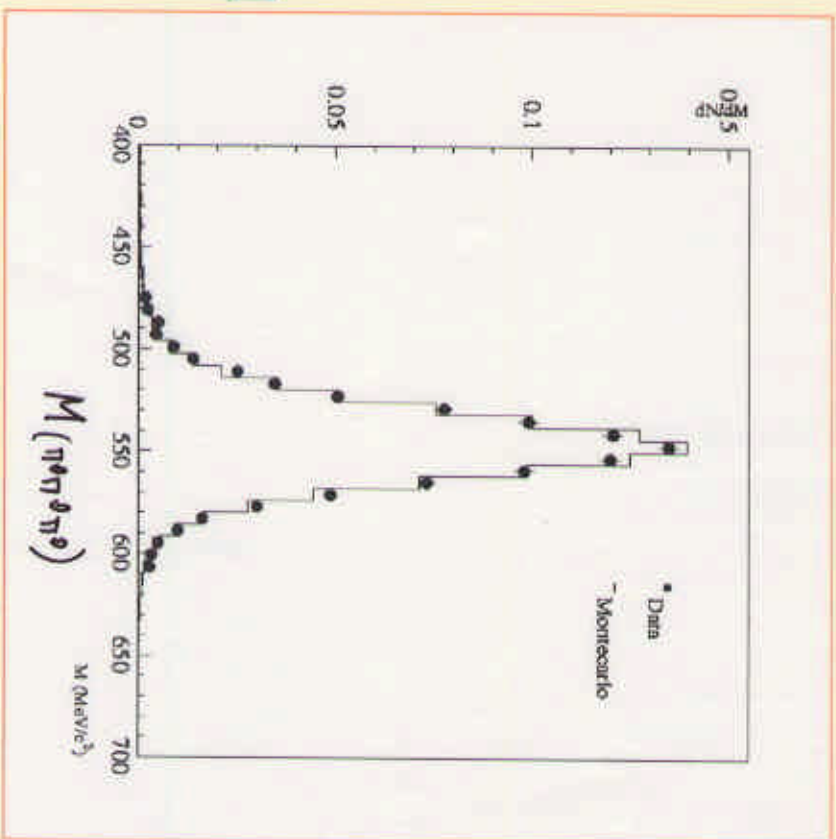
- $\phi \rightarrow \eta \gamma \rightarrow \pi^+ \pi^- \gamma \gamma \gamma$  ( $\eta \rightarrow \pi^+ \pi^- \pi^0$ )  **$\text{Br} = 2.9 \times 10^{-3}$**
- $\phi \rightarrow \eta' \gamma \rightarrow \pi^+ \pi^- \gamma \gamma \gamma$  ( $\eta' \rightarrow \pi^+ \pi^- \eta$ ;  $\eta \rightarrow \gamma \gamma$ )  **$\text{Br} \approx 2 \times 10^{-5}$**
- Analyzed sample =  **$2.4 \text{ pb}^{-1}$**
- $\epsilon_{\eta' \gamma} = 19\%$        $\epsilon_{\eta \gamma} = 32\%$
- $N_{\eta'} = 21 \pm 4.6$  events
- $N_{\eta} = 6696$  events
- $R_{\phi} = (7.1 \pm 1.6 \pm 0.3) \times 10^{-3}$
- $\text{Br}(\phi \rightarrow \eta' \gamma) = R_{\phi} \text{Br}(\phi \rightarrow \eta \gamma) =$   
 $= (8.9 \pm 2.0 \pm 0.6) \times 10^{-5}$



## $\phi \rightarrow \eta \gamma, \eta' \gamma$ (neutral final state)



- $\phi \rightarrow \eta \gamma \rightarrow 7 \gamma$  ( $\eta \rightarrow \pi^0 \pi^0 \pi^0$ )  $\text{Br} = 3.9 \times 10^{-3}$
  - $\phi \rightarrow \eta' \gamma \rightarrow 7 \gamma$  ( $\eta' \rightarrow \pi^0 \pi^0 \eta$ ;  $\eta \rightarrow \gamma \gamma$ )  $\text{Br} \approx 10^{-5}$
  - Analyzed sample =  $2.4 \text{ pb}^{-1}$
  - $\epsilon_{\eta \gamma} = 41\%$   $\epsilon_{\eta' \gamma} = 13\%$
  - $N_{\eta} = 10938$  events
  - $N_{\eta'} = 6^{+3.3}_{-2.2}$  First observation
  - $R_{\phi} = (6.9^{+3.8}_{-2.5} \pm 0.9) \times 10^{-3}$
- Combining the ch. and neutral final states:
- $g_p = (-18.9^{+3.6}_{-2.8} \pm 0.6)^{\circ}$





## $\phi \rightarrow \pi^+ \pi^- \pi^0$

- $\text{Br}(\phi \rightarrow \pi^+ \pi^- \pi^0) \approx 15\%$
- $\phi \rightarrow \rho \pi$  (all charge states)
- $\phi \rightarrow \pi^+ \pi^- \pi^0$  – direct decay
- $e^+e^- \rightarrow \omega \pi^0$ ;  $\omega \rightarrow \pi^+ \pi^-$  (bckg)
- 330000 evts

in the  $L=2.1 \text{ pb}^{-1}$  sample

- **Fit of the Dalitz plot to :**

$$f(X, Y) = |\vec{p}^+ \times \vec{p}^-|^2 |A_{\rho\pi} + A_{\text{direct}} + A_{\omega\pi}|^2$$

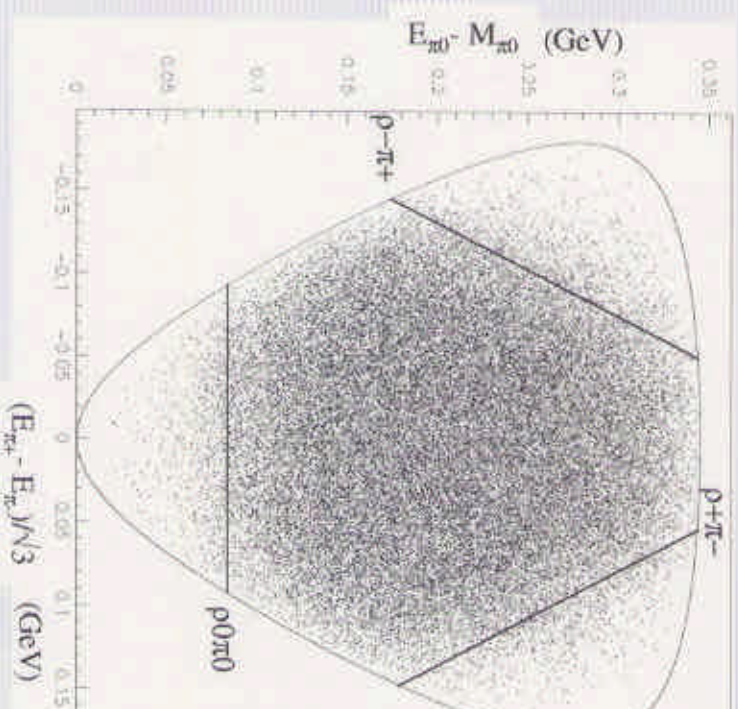
Free parameters:

$M_{\rho^0}$ ,  $\Delta M$  ( $M_{\rho^\pm} - M_{\rho^0}$ ),  $\Gamma_\rho$ , **modulus**

**and phase for the direct term,**

**mod. and phase for the  $\omega\pi^0$  term**

**( $\omega$  mass and width fixed)**



Parameter	Fit result	PDG result
$M(\rho^0)$ (MeV)	$776.1 \pm 1.0$	$776.0 \pm 0.9^*$
$\Delta M$ (MeV)	$-0.5 \pm 0.7$	$0.1 \pm 0.9$
$\Gamma(\rho)$ (MeV)	$145.6 \pm 2.2$	$150.9 \pm 2.0$
$A(\text{direct term})/A(\rho\pi)$	$0.10 \pm 0.01$	$-0.15 \div 0.11$
$\text{fase}(\text{direct term}) - \text{fase}(\rho\pi)$	$(114 \pm 12)^\circ$	



## Conclusions

- **L = 2.4 pb<sup>-1</sup> collected with the KLOE detector in 1999**
- **Radiative decays of  $\phi$  have been studied:**
  - $\phi \rightarrow f_0 \gamma, \phi \rightarrow a_0 \gamma$
  - $\phi \rightarrow \eta \gamma, \phi \rightarrow \eta' \gamma$
- **Study of the Dalitz plot of  $\phi \rightarrow \pi^+ \pi^- \pi^0$**
- **Statistical accuracy is comparable to the VEPP-2M results**
- **Work is in progress to reduce systematic uncertainties**
- **New data-taking has started one month ago**  
 $\Rightarrow$  **higher statistics will be available in next future**