

# CHARGE ASYMMETRY AND RADIATIVE $\phi$ DECAYS

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hep-ph/0412239

## I Importance of FSR

→ sQED

→  $e^+e^- \rightarrow \phi^* \rightarrow (f_0(980)_{f_0} + f_0(600)_{\sigma})\gamma$

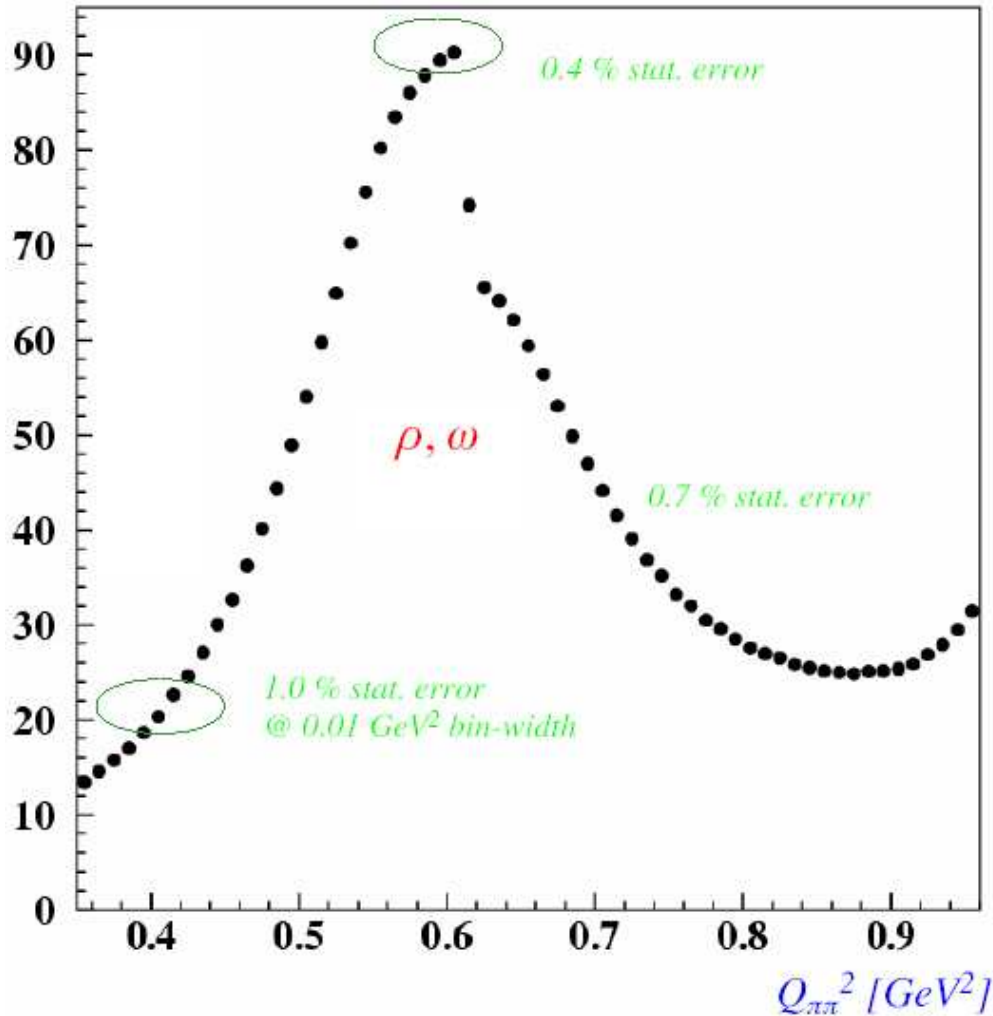
→  $\pi\pi\gamma$

## II Charge asymmetries

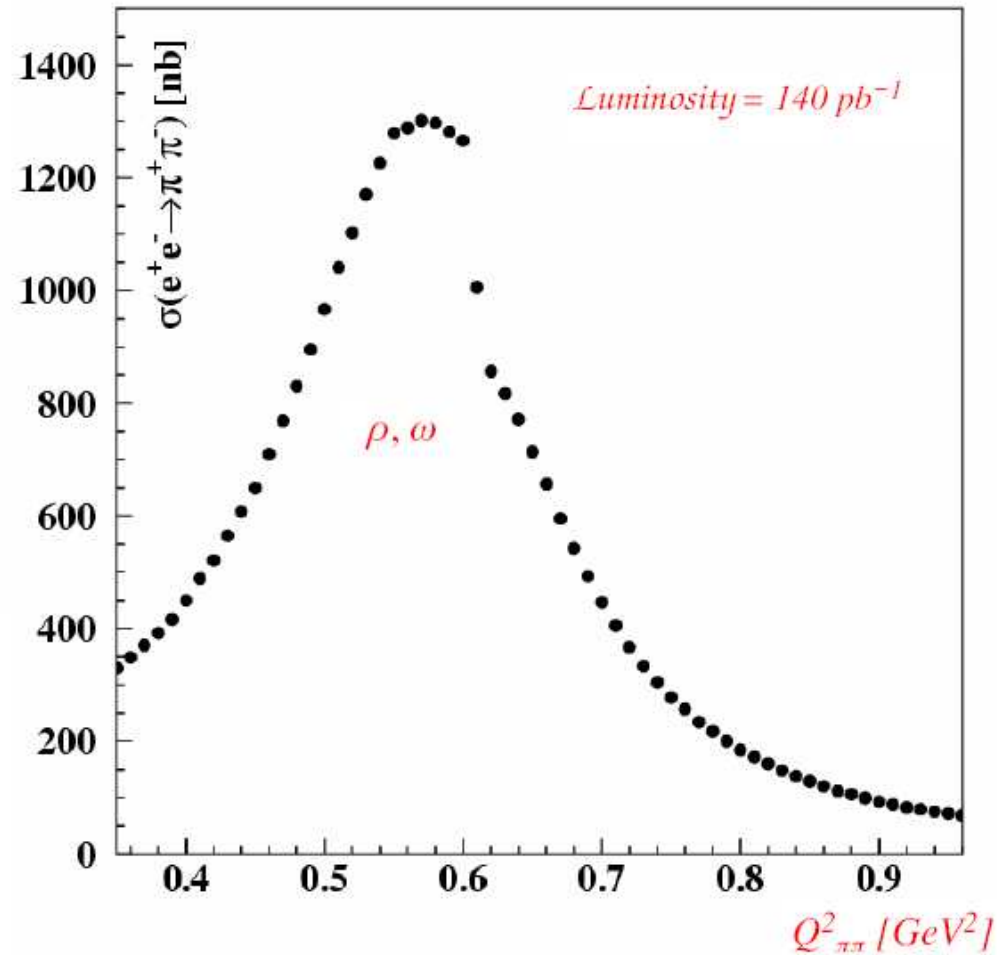
## III Summary

# KLOE: Phys.Lett.B606 (2005) 12.

$$d\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \gamma) / (dQ_{\pi\pi}^2) \text{ (nb / GeV}^2\text{)}$$

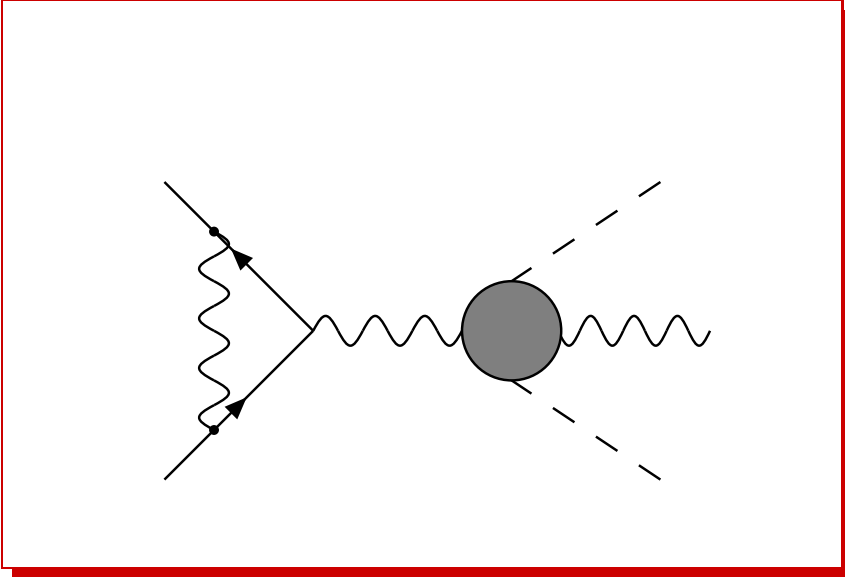
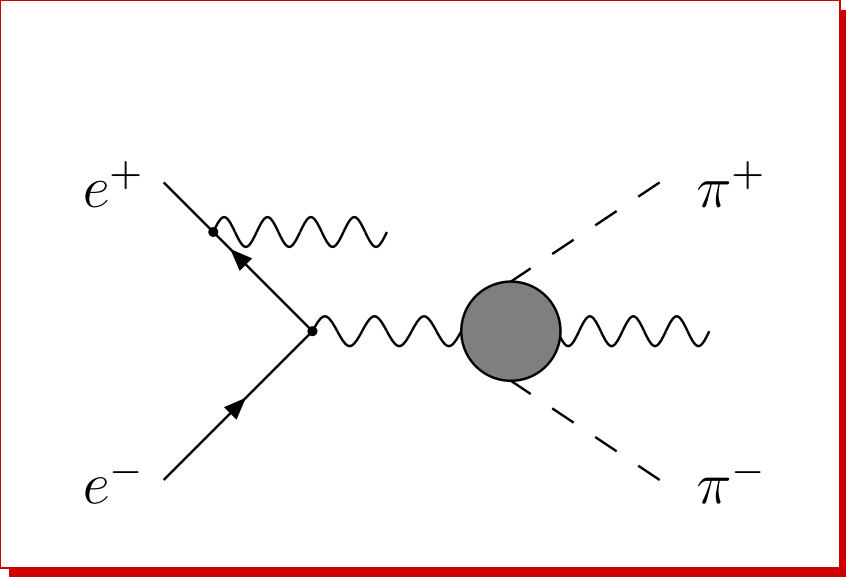
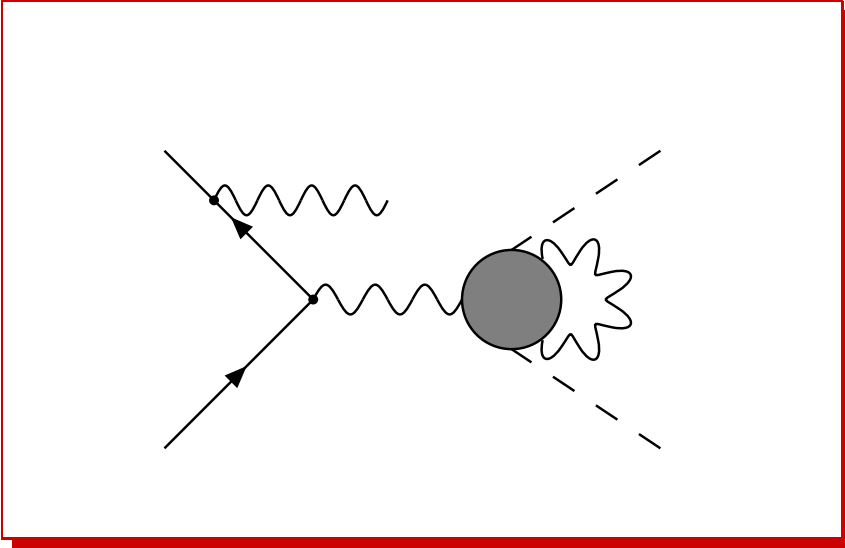
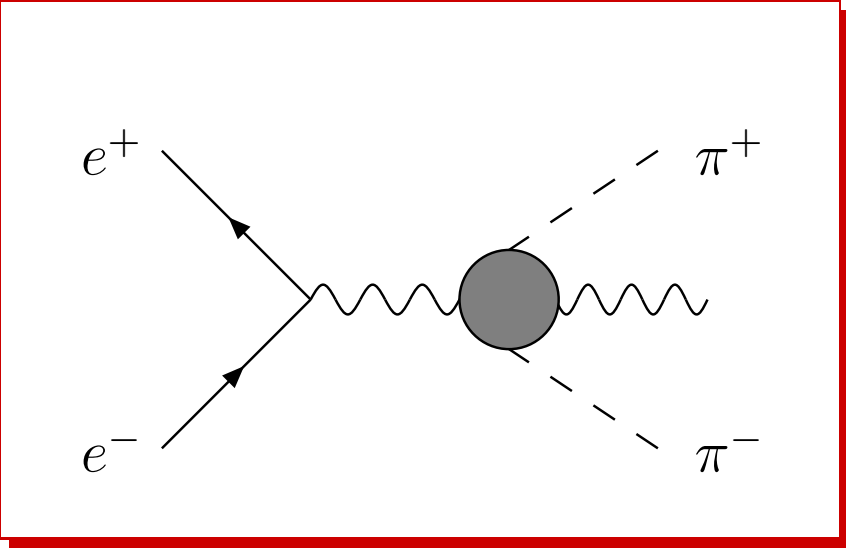


$$d\sigma(e^+ e^- \rightarrow \pi^+ \pi^-) / (dQ_{\pi\pi}^2) \text{ (nb / GeV}^2\text{)}$$



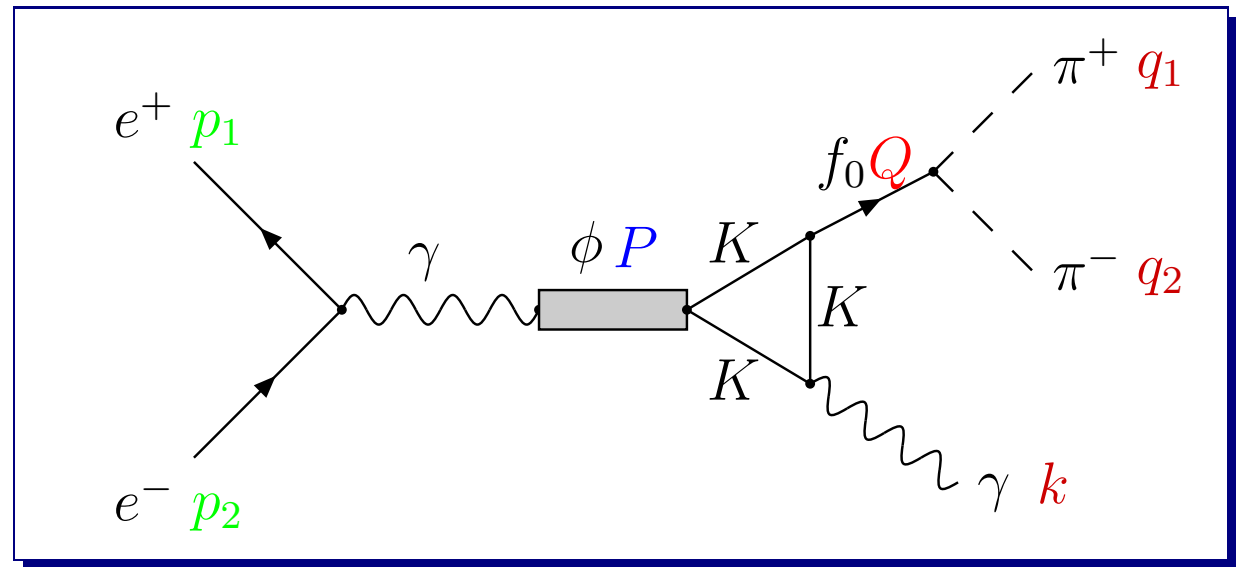
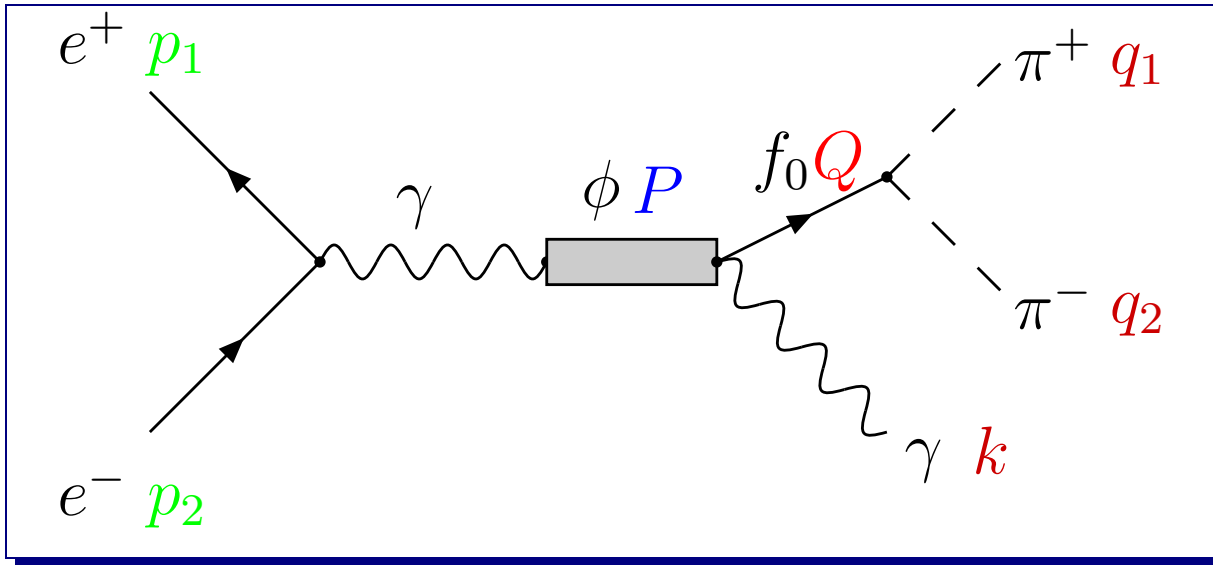
$$a_{\mu}^{\pi\pi} = (375.6 \pm 0.8_{stat} \pm 4.8_{syst.+theor}) \cdot 10^{-10}, \quad \text{theor. syst. error} = 0.9\%$$

# FSR in PHOKHARA



# FSR at KLOE, additional contributions:

$$e^+e^- \rightarrow \phi^* \rightarrow (f_0(980)f_0 + f_0(600)\sigma)\gamma \rightarrow \pi\pi\gamma$$



**FSR:**  $e^+e^- \rightarrow \phi^* \rightarrow (f_0(980)_{f_0} + f_0(600)_{\sigma})\gamma \rightarrow \pi\pi\gamma$

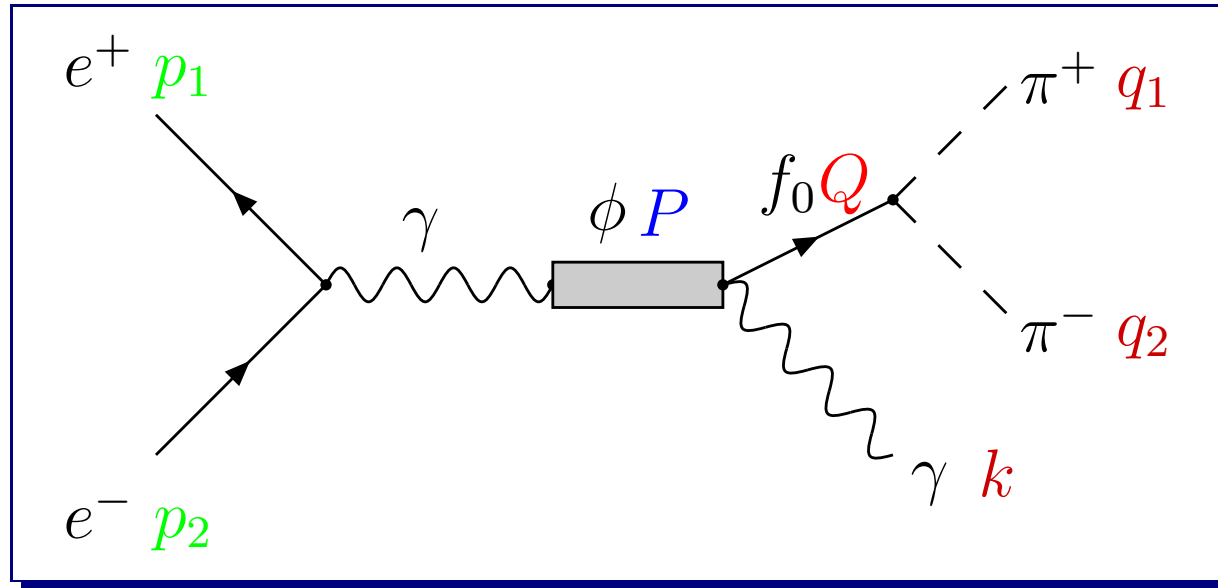
$$\mathcal{M}_{sQED} = \frac{ie^3}{s} \bar{v}(p_1) \gamma_\mu u(p_2) \left\{ (q_1 + k - q_2)^\mu \frac{q_1 \cdot \epsilon^*(\gamma)}{q_1 \cdot k} + (q_2 + k - q_1)^\mu \frac{q_2 \cdot \epsilon^*(\gamma)}{q_2 \cdot k} - 2\epsilon^{*\mu}(\gamma) \right\} F_{2\pi}(s)$$

**K. Melnikov, F. Nguyen, B. Valeriani, and G. Venanzoni, Phys.Lett.B477(2000):**

$$\mathcal{M}_{e^+e^-}(\phi) = \frac{ie^3}{s} \bar{v}(p_1) \gamma_\mu u(p_2) e^{i\alpha_\phi} \times \frac{g_{\phi\gamma}}{M_\phi^2 - s - iM_\phi\Gamma_\phi} f_\phi(Q^2) d^{\mu\alpha} \epsilon_\alpha^*(\gamma)$$

$$d^{\mu\alpha} = (P \cdot k)g^{\mu\alpha} - k^\mu P^\alpha, \quad P = Q + k, \quad Q = q_1 + q_2$$

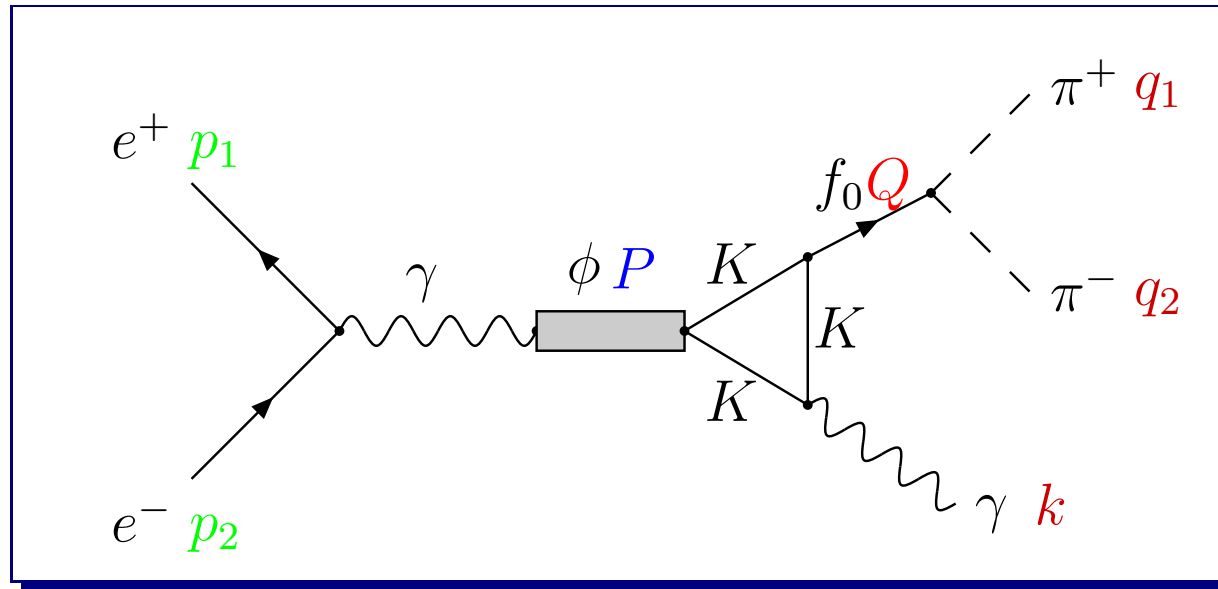
# 1. 'no structure' model



$$f_\phi(Q^2) = \frac{g_\phi f_0 \gamma g_{f_0 \pi \pi}}{M_{f_0}^2 - Q^2 - i M_{f_0} \Gamma_{f_0}} + e^{i\alpha_\phi} \frac{g_{\phi \sigma} \gamma g_{\sigma \pi \pi}}{M_\sigma^2 - Q^2 - i M_\sigma \Gamma_\sigma}$$

$\alpha_\phi$  - constant

## 2. $K^+K^-$ model



$$f_\phi(Q^2) = \frac{g_{\phi K^+K^-}}{2\pi^2 m_K^2} I\left(\frac{M_\phi^2}{m_K^2}, \frac{Q^2}{m_K^2}\right) \times \left[ \frac{g_{f_0 K^+K^-} - g_{f_0 \pi\pi}}{M_{f_0}^2 - Q^2 - iM_{f_0}\Gamma_{f_0}} + e^{i\alpha_\sigma} \frac{g_{\sigma K^+K^-} - g_{\sigma \pi\pi}}{M_\sigma^2 - Q^2 - iM_\sigma\Gamma_\sigma} \right]$$

$$\alpha_\phi = b\sqrt{s - 4m_\pi^2}, \quad b = 75^\circ/\text{GeV}$$

# Fit to experimental data

A. Aloisio *et al.*, [KLOE Collaboration],  
Phys.Lett.B537(2002)21

V.M. Aulchenko *et al.*, [SND Collaboration],  
Phys.Lett.B440(1998)442

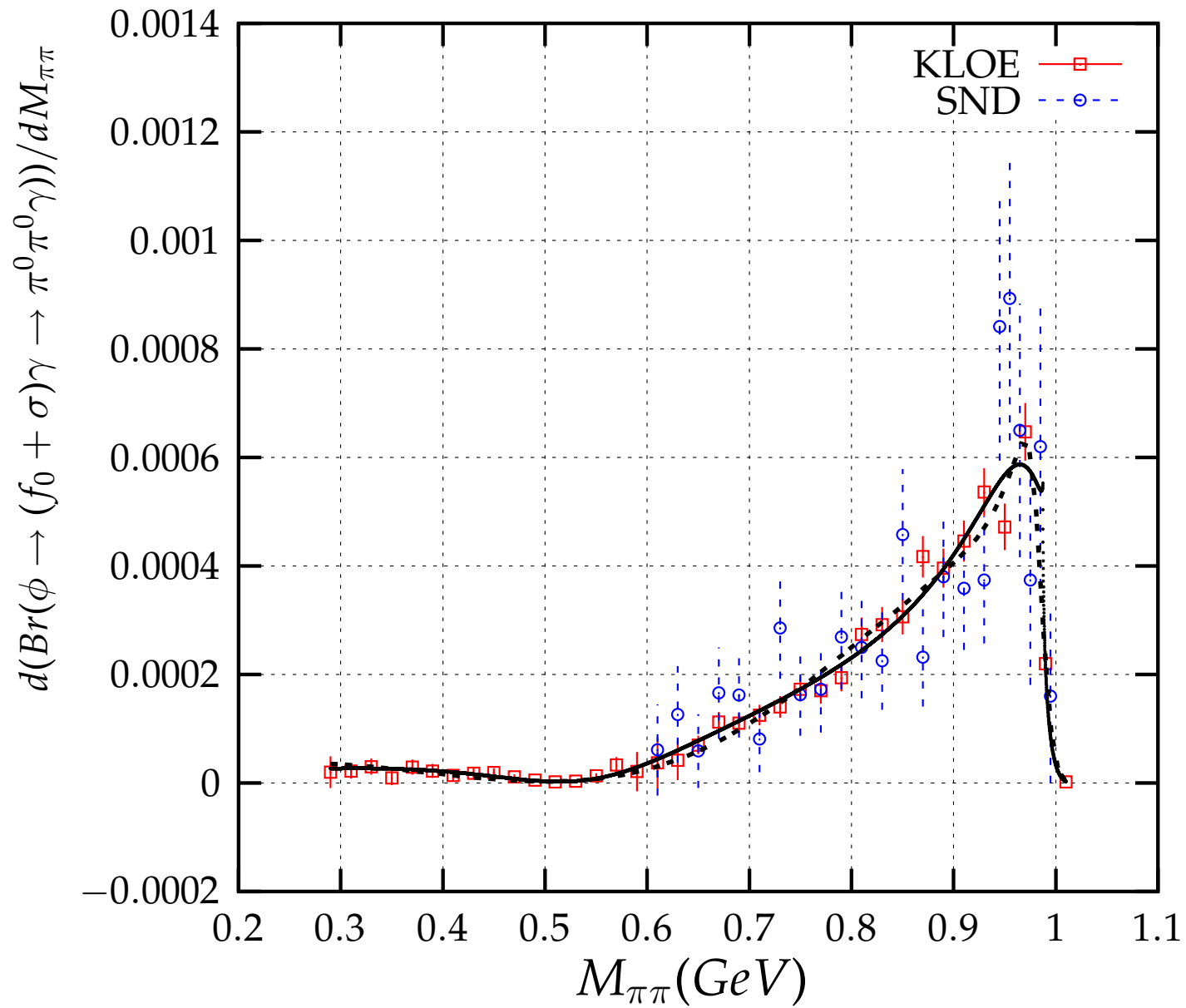
$$\frac{dBr(\phi \rightarrow (f_0 + \sigma) \gamma \rightarrow \pi^0 \pi^0 \gamma)}{dM_{\pi\pi}}$$

$$\mathcal{M}_\phi = -ie f_\phi(Q^2) \epsilon_\mu(\phi) d^{\mu\alpha} \epsilon_\alpha^*(\gamma)$$



# Parameters

	'no structure'	' $K^+K^-$ '
$M_{f_0}$ [MeV]	$983.9 \pm 1.4$	$1003 \pm 8$
$\Gamma_{f_0}$ [MeV]	$35.4 \pm 3.2$	$108 \pm 7$
$M_\sigma$ [MeV]	$588 \pm 145$	$519 \pm 23$
$\Gamma_\sigma$ [MeV]	$1653 \pm 921$	$319 \pm 65$
$\alpha_\sigma$	$(101 \pm 11)^\circ$	$(98 \pm 8)^\circ$
$g_{\phi f_0 \gamma} g_{f_0 \pi \pi}$	$2.84 \pm 0.17$	-
$g_{\phi \sigma \gamma} g_{\sigma \pi \pi}$	$4.0 \pm 1.5$	-
$g_{\phi K^+ K^-} g_{f_0 K^+ K^-} g_{f_0 \pi \pi}$ [GeV <sup>2</sup> ]	-	$59.4 \pm 5.1$
$g_{\phi K^+ K^-} g_{\sigma K^+ K^-} g_{\sigma \pi \pi}$ [GeV <sup>2</sup> ]	-	$7.9 \pm 2.0$
$\chi^2/(53 \text{ d.o.f.})$	<b>38</b>	<b>29</b>



# Charge asymmetries

⇒ forward-backward asymmetry defined for  $\pi^+$

$$\mathcal{A}_{FB}(Q^2) = \frac{N(\theta_{\pi^+} > 90^\circ) - N(\theta_{\pi^+} < 90^\circ)}{N(\theta_{\pi^+} > 90^\circ) + N(\theta_{\pi^+} < 90^\circ)} (Q^2)$$

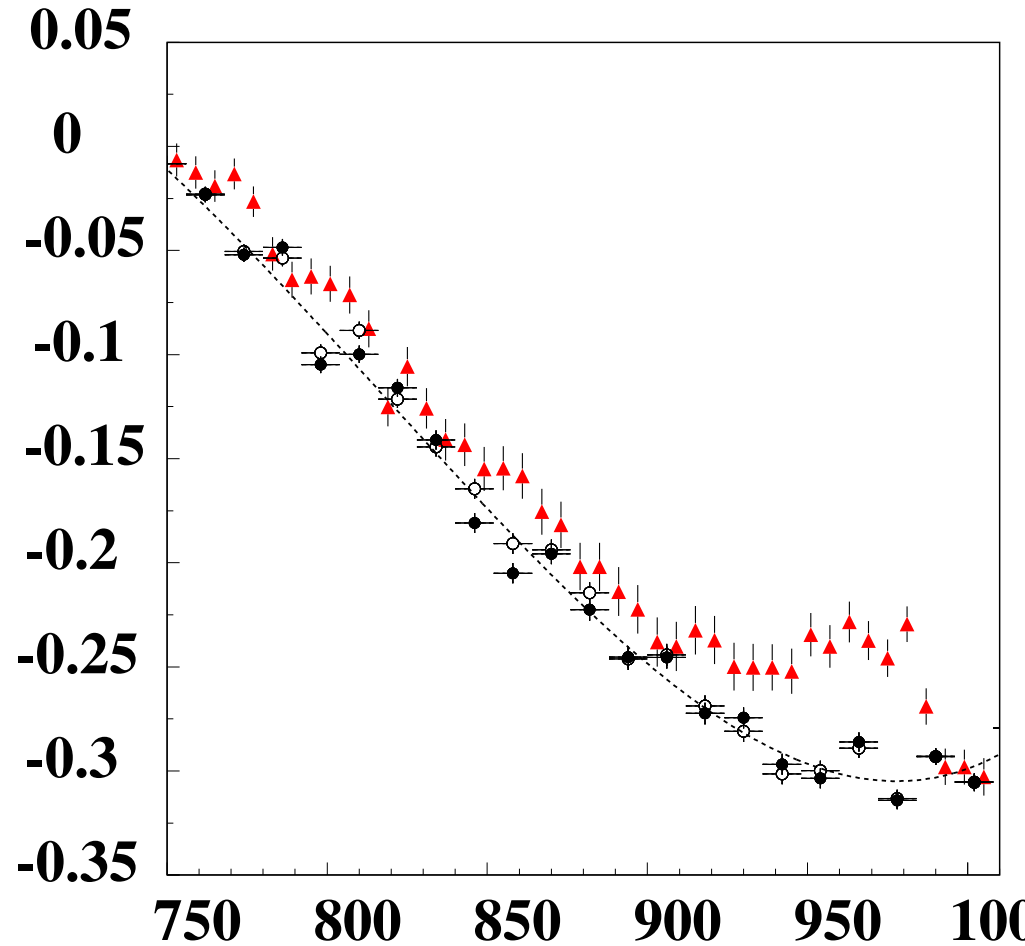
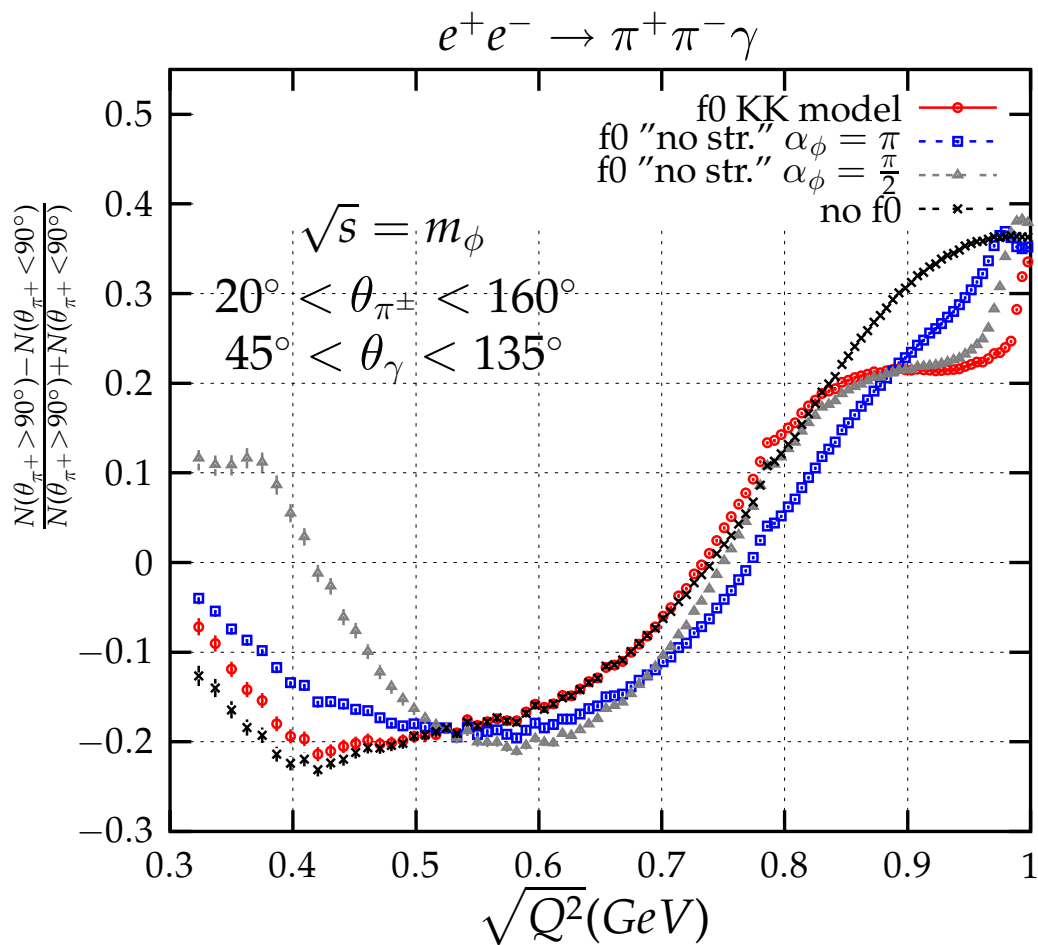
⇒ charge asymmetry

$$\mathcal{A}_C(\theta_\pi) = \frac{N(\pi^+) - N(\pi^-)}{N(\pi^+) + N(\pi^-)} (\theta_\pi)$$

# forward-backward asymmetry

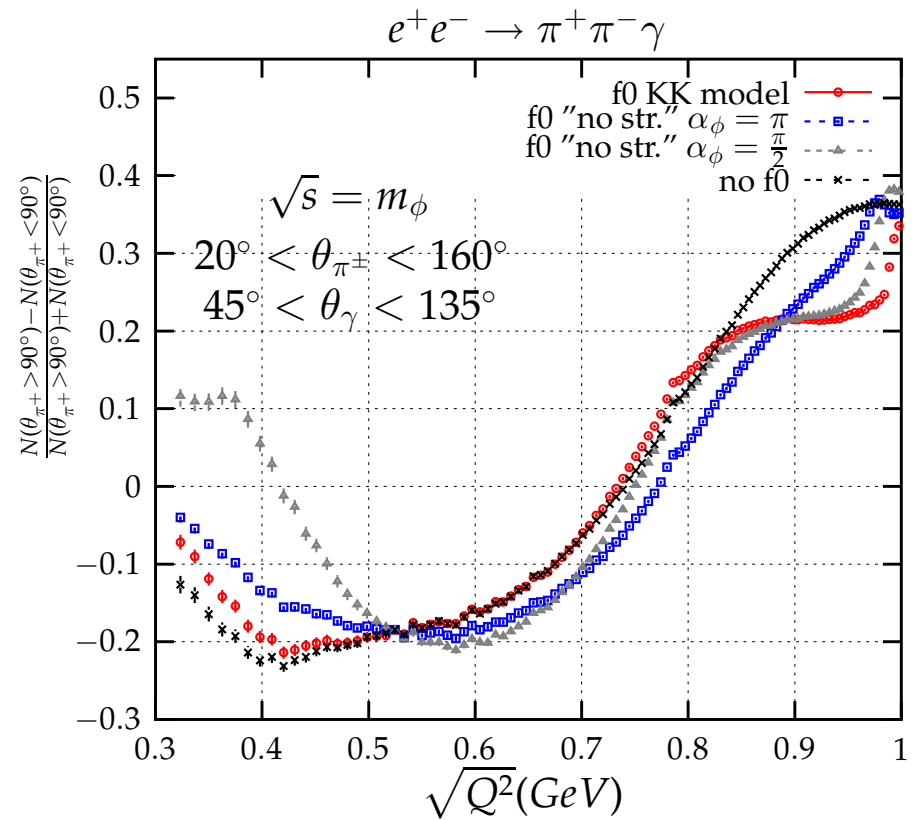
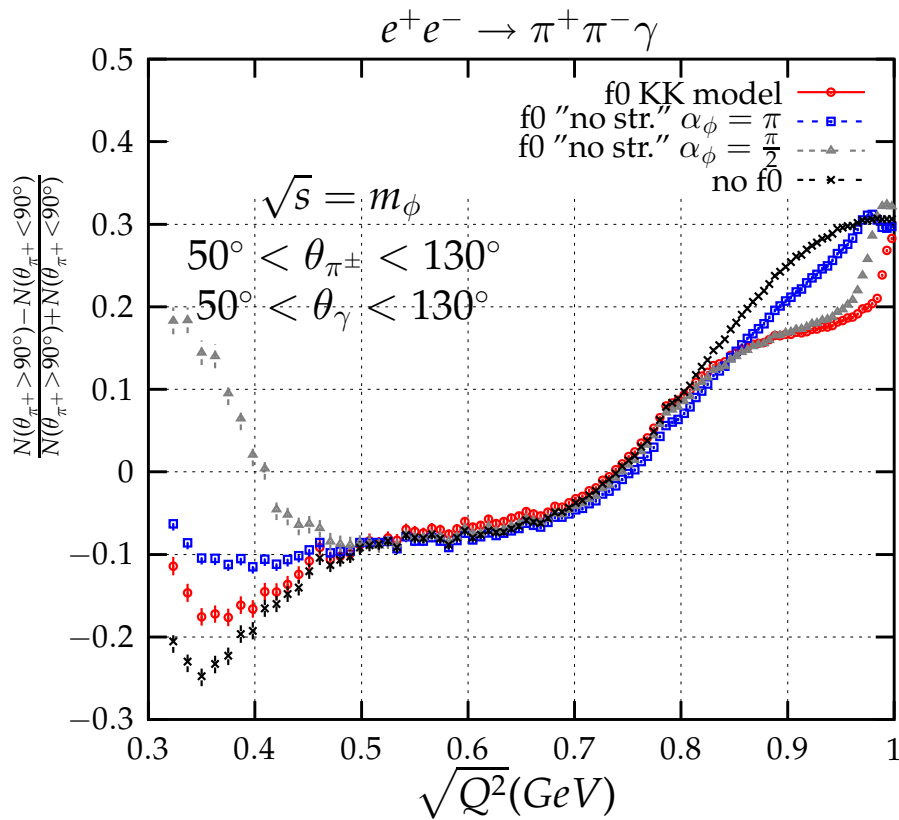
z- axis along  $e^+$

KLOE preliminary: hep-ex/0410072



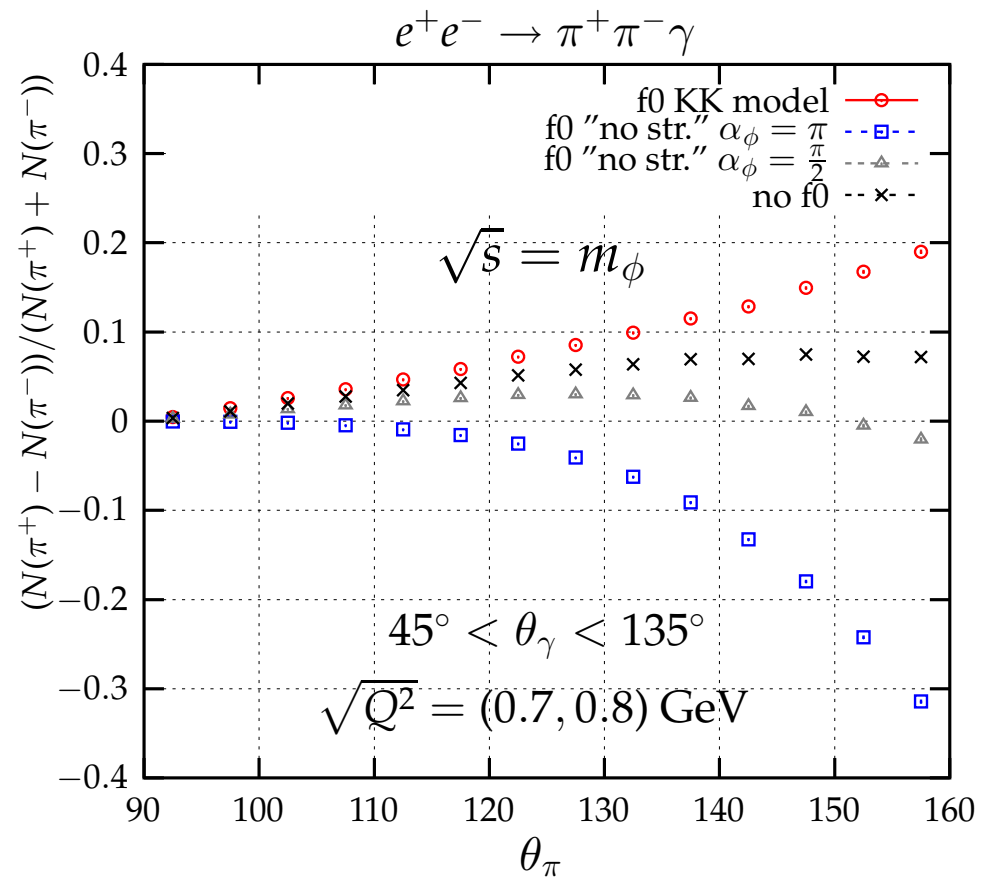
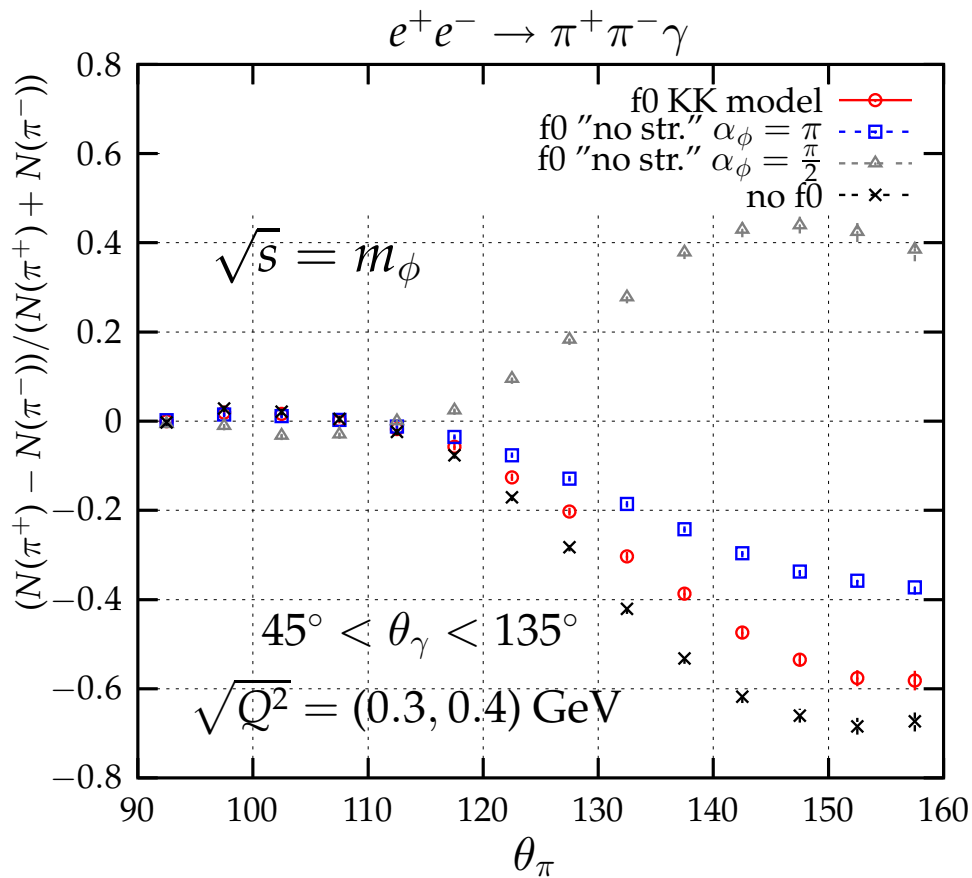
# forward-backward asymmetry

effects depend on a chosen event selection

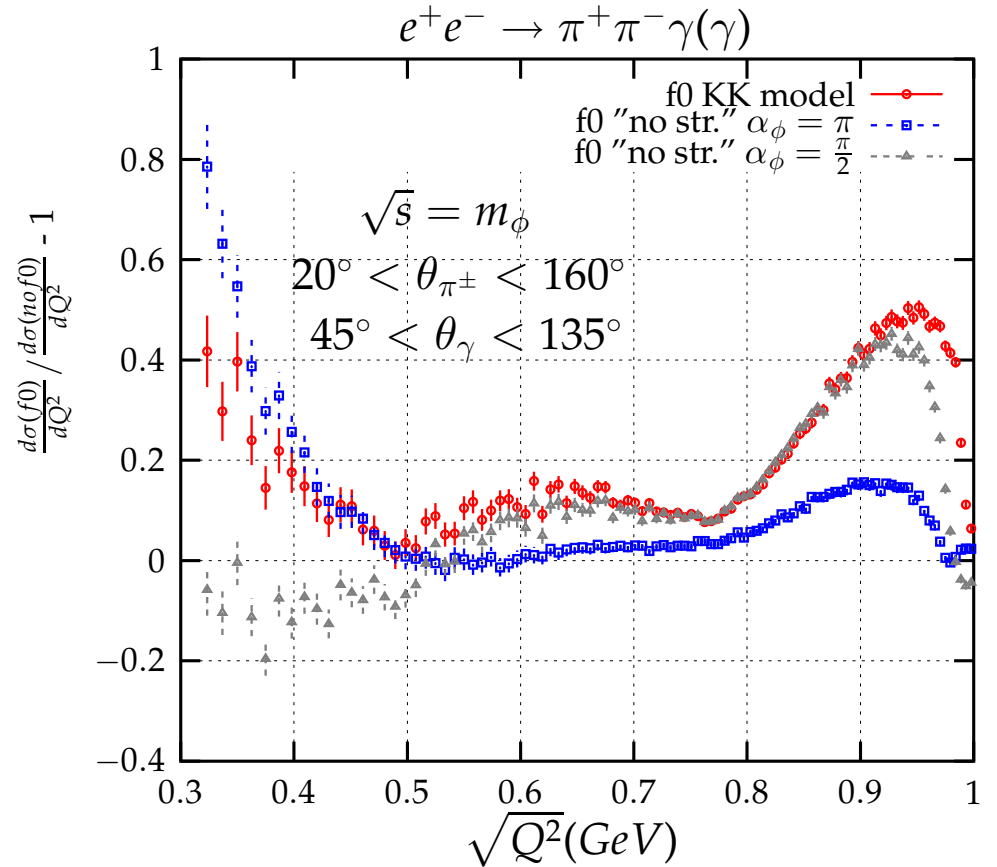
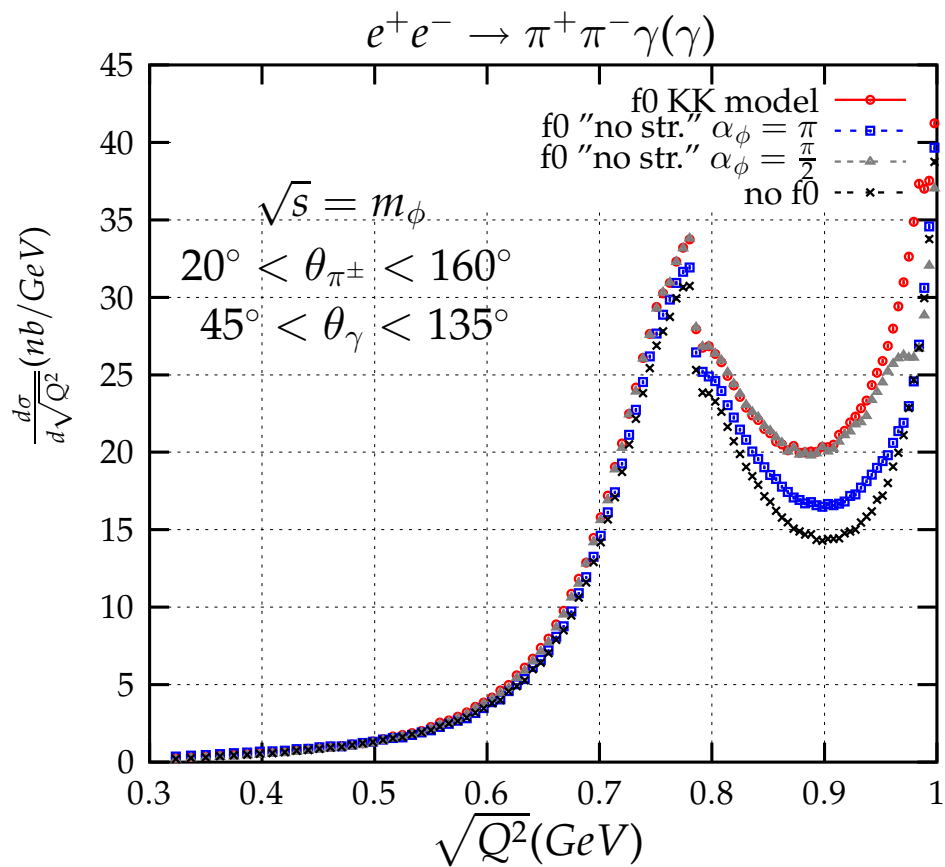


# charge asymmetry

effects bigger at low  $\theta_\pi$

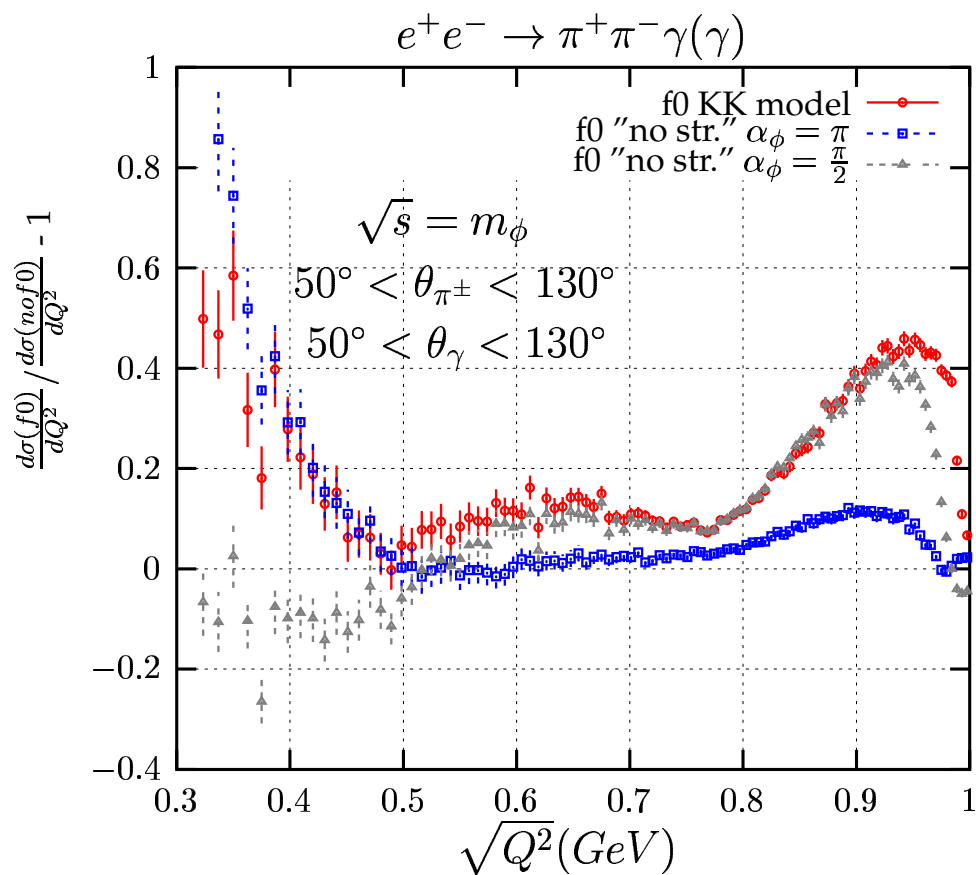
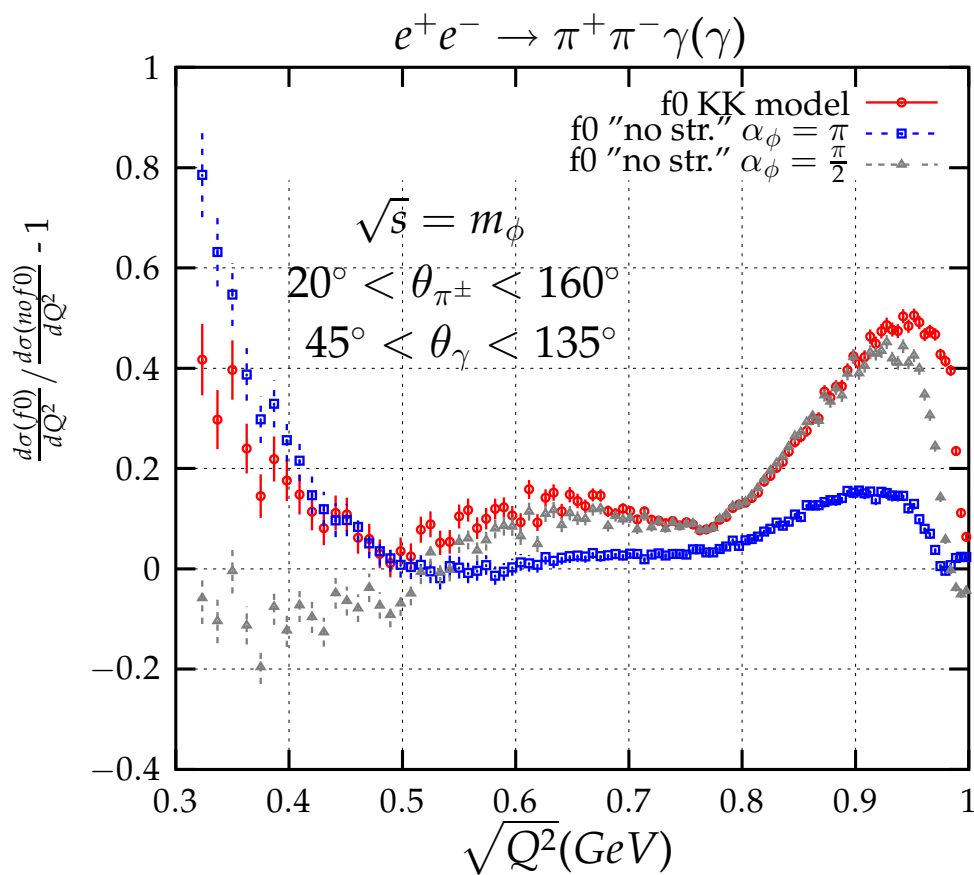


# Cross section



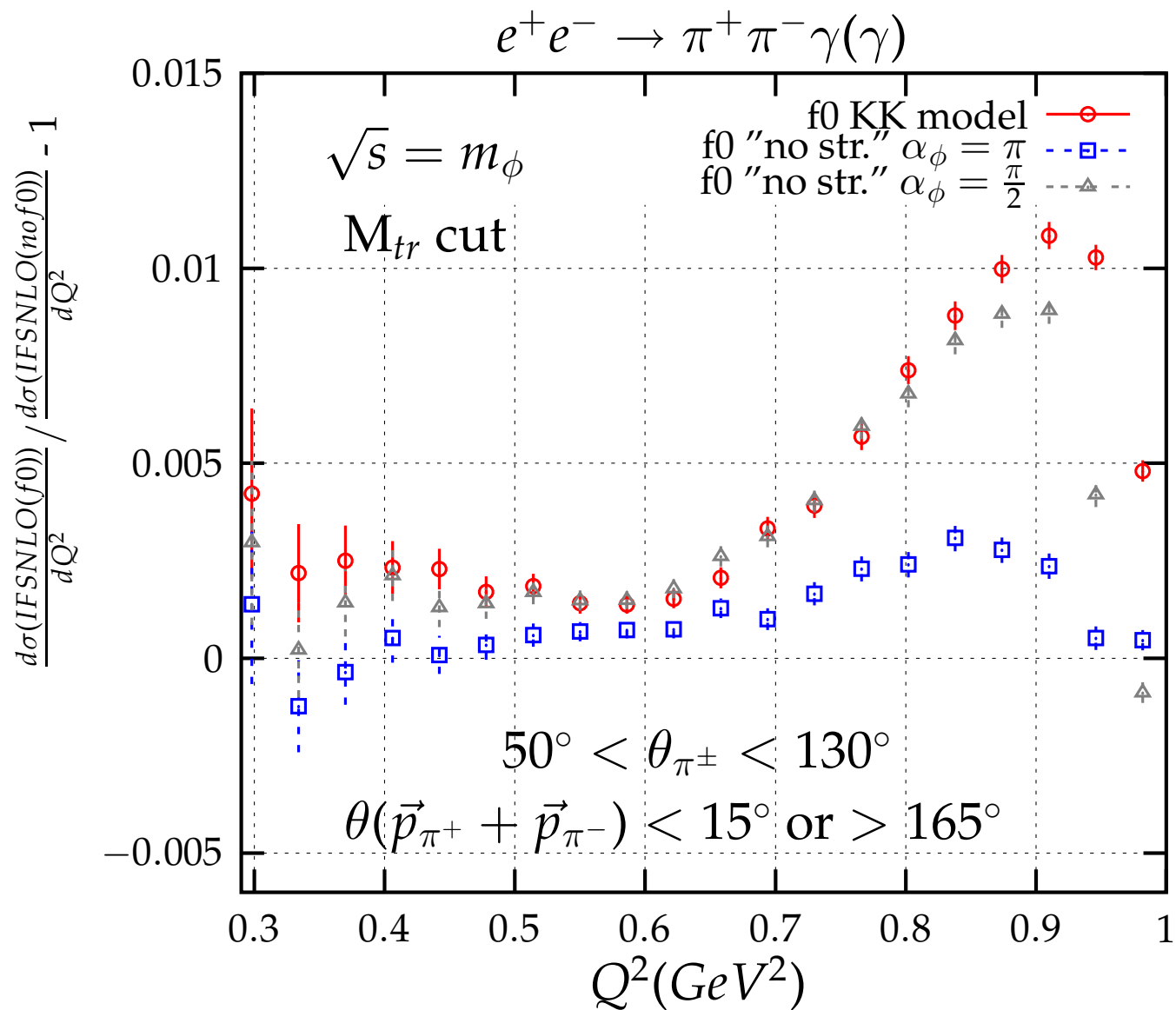
# Cross section

again effects depend on a chosen event selection





# KLOE event selection



# Summary

⇒ **new important contributions to FSR were studied**

⇒ **charge asymmetries can differentiate between the models of radiative  $\phi$  decays**