



*Search for the $\phi \rightarrow (f_0 + a_0)\gamma \rightarrow K_s K_s \gamma$
decay at KLOE*

*Salvatore Fiore
Sapienza Università di Roma*

(for the KLOE collaboration)

What we are looking for



- At Φ -factories, $K_0\bar{K}_0$ pairs can be produced in a $J^{PC} = 0^{++}$ state

$$\begin{aligned} |i_+\rangle &= \frac{1}{\sqrt{2}}(|K^0(+p)\rangle|\bar{K}^0(-p)\rangle + |\bar{K}^0(p)\rangle|K^0(-p)\rangle) \\ &= \frac{N}{\sqrt{2}}(|K_S(+p)\rangle|K_S(-p)\rangle - |K_L(p)\rangle|K_L(-p)\rangle) \end{aligned}$$

through $f_0(980)$, $a_0(980)$ scalar mesons' decays
from ϕ radiative decays

- We look for $\Phi \rightarrow K_S K_S \gamma \rightarrow \pi^+ \pi^- \pi^+ \pi^- \gamma$ events
(B.R. ($K_S \rightarrow \pi^+ \pi^-$) = 0.686)

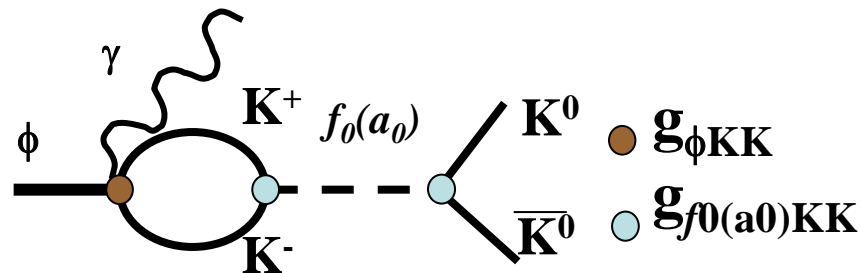
Never measured before !

Theoretical models



- Kaon Loop model:* Φ meson couples to $f_0(a_0)$ through a charged kaon loop

$$\Phi \rightarrow (f_0 + a_0)\gamma \rightarrow K^0 \bar{K}^0 \gamma \text{ (} K^0 \bar{K}^0 \text{ loop model)}$$



$$\frac{d\Gamma_s}{dm} \propto \frac{m}{s\sqrt{s}} \left| g(m^2) \left(\frac{g_{f_0 K^0 K^0 \bar{K}^0}^2}{D_{f_0}(t)} - \frac{g_{a_0 K^0 K^0 \bar{K}^0}^2}{D_{a_0}(t)} \right) \right|^2 \times (s-t) b \sqrt{1 - \frac{4m_{K^0}^2}{m^2}}$$

$$\text{BR}(\Phi \rightarrow (f_0 + a_0)\gamma \rightarrow K^0 \bar{K}^0 \gamma) = (1.3 \div 4.4) \times 10^{-8}$$

(Achasov, Gubin Phys.Rev.D64:094016,2001)



- **Linear sigma model:** same graph as kaon loop, different coupling evaluations for $g_{\phi KK}$ and

$g_{f_0(a_0)KK}$

Escribano's estimate for this B.R. is $7.5 \cdot 10^{-8}$

(Escribano, hep-ph/0607325)

- **Radiative VMD in χ PT:** chiral effective Lagrangian including on-shell vector mesons

Bramon et al's estimate for this B.R. is $7.6 \cdot 10^{-9}$

(Bramon, Grau, Pancheri, Phys.Lett.B289,97 (1992))

Theoretical models (3)



- **Unitarized χ PT:**
Oller's B.R. estimate in this framework is $5 \cdot 10^{-8}$
(Oller, Phys.Lett.B426,7 (1998))
- **Kaon Loop phenomenological approach:** kaon loop, coupling evaluations using exp. data including KLOE's
Gokapl et al.'s range for this B.R. is $1.4 \cdot 10^{-7} \div 1.2 \cdot 10^{-8}$
(Gokalp, Korkmaz, Yilmaz, hep-ph/0702214)

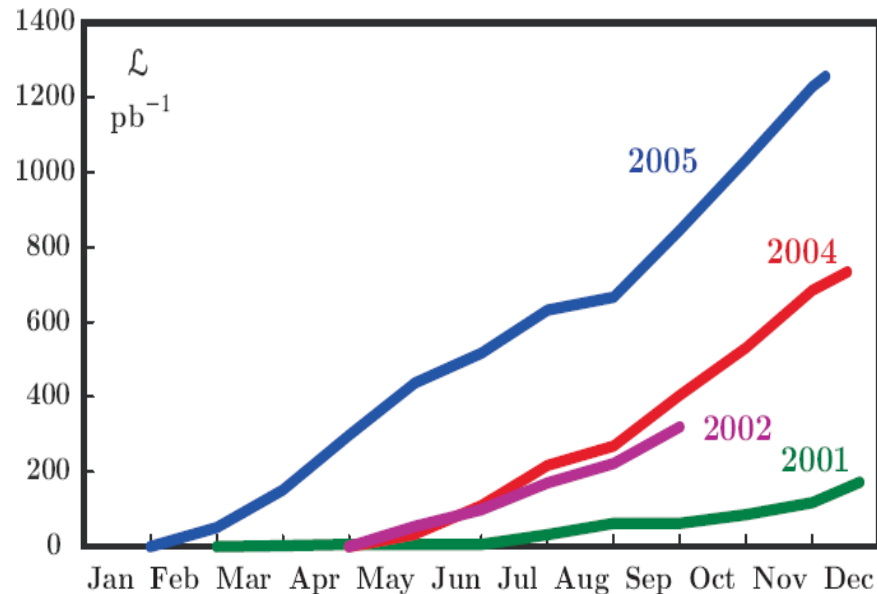
DATA sample



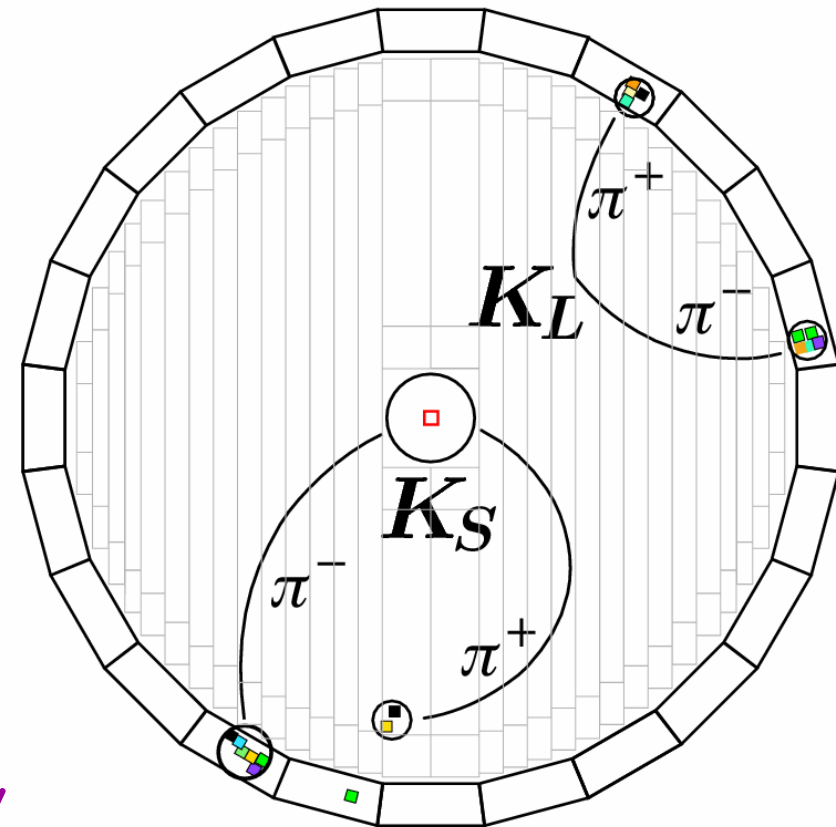
Integrated Luminosity 2001-5

$$\int L dt = 2.5 \text{ fb}^{-1}$$

$$L_{\text{peak}} = 1.5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$$



Example of K_L tagged by $K_S \rightarrow \pi^+\pi^-$ vertex at IP



This analysis: events selected by neutral kaon tagging algorithms

MonteCarlo generations



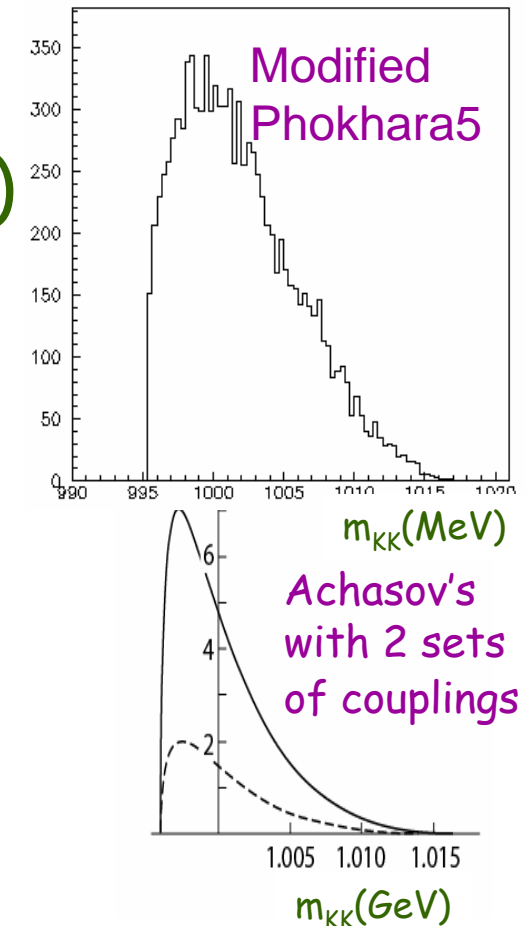
Signal:

- **Modified Phokhara5 MC (10k events)**

(G.Rodrigo, Nucl.Phys.Proc.Suppl.169,271 (2007))

Implemented model:
$$\frac{d\Gamma_s}{dm} \propto E_\gamma^3 \sqrt{1 - \frac{4m_{K_0}^2}{m^2}}$$

two K_s generated with both K_s decaying in $\pi^+\pi^-$



Background:

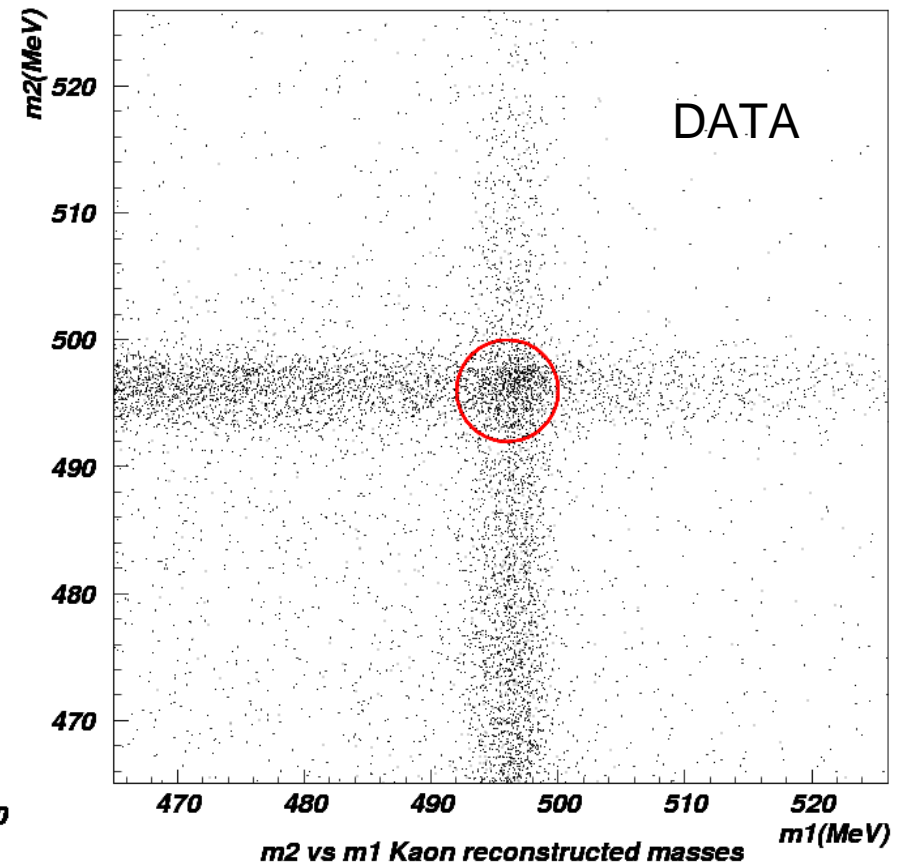
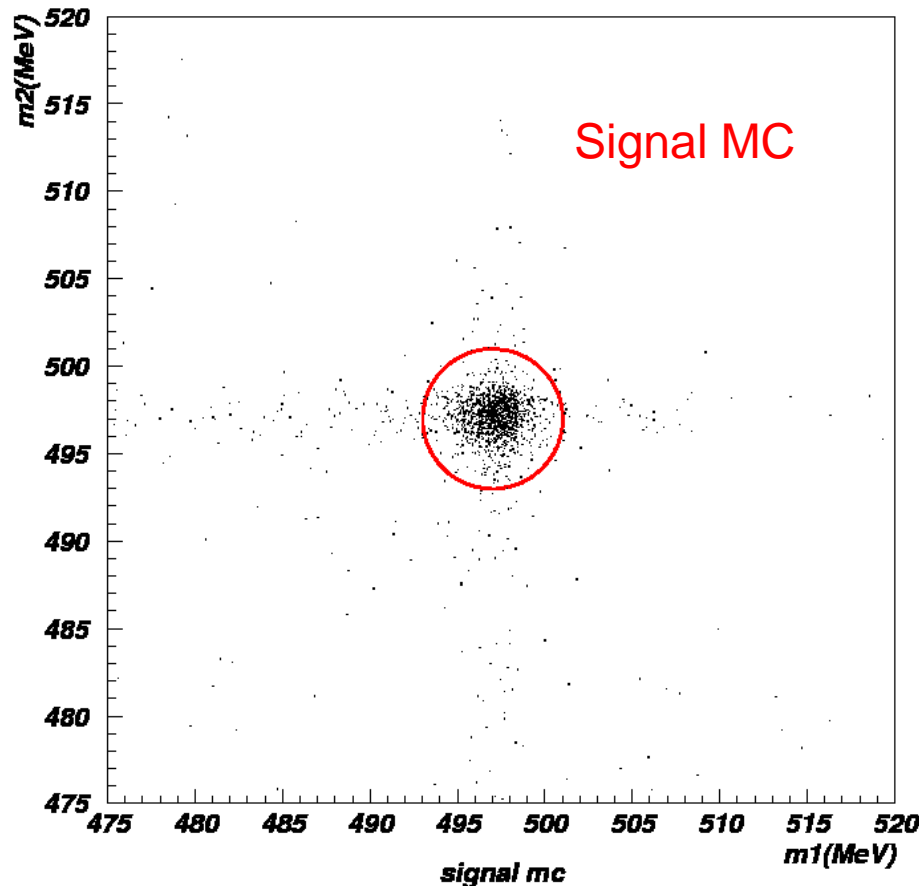
- same statistics of DATA
- run-by-run data taking conditions simulated
- ϕ decays
- $e^+e^- \rightarrow 4\pi$ according to phase space

Signal selection and background rejection



- **Vertices:** two inside a fiducial volume of 3cm radius and ± 8 cm in z around beam interaction point ($\lambda_{K_S} < 0.6$ cm)
- **# of tracks:** two tracks attached to each vertex are required
- **K_S invariant mass** reconstructed by $\pi^+\pi^-$ tracks for both K_S
- **Kaon pair** invariant mass selection and kinematic constraints
- **Photon request:**
 - **One cluster not associated** with tracks
 - **Cluster energy** compatible with missing momentum and **good timing**
 - **"photon" direction** compatible with $K_S K_S$ momentum

$K_S(1)$ vs $K_S(2)$ invariant mass

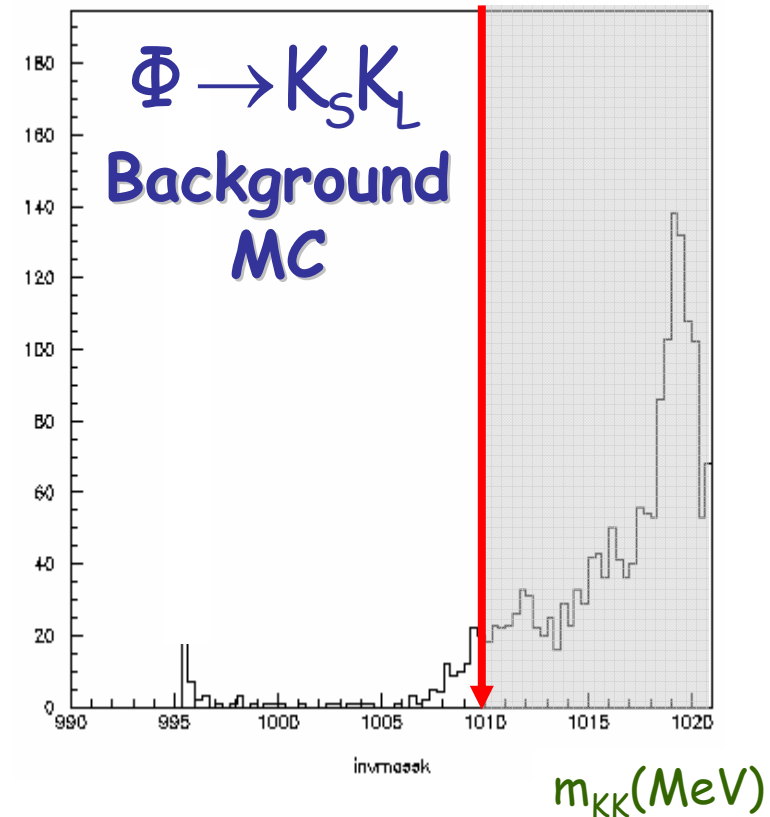
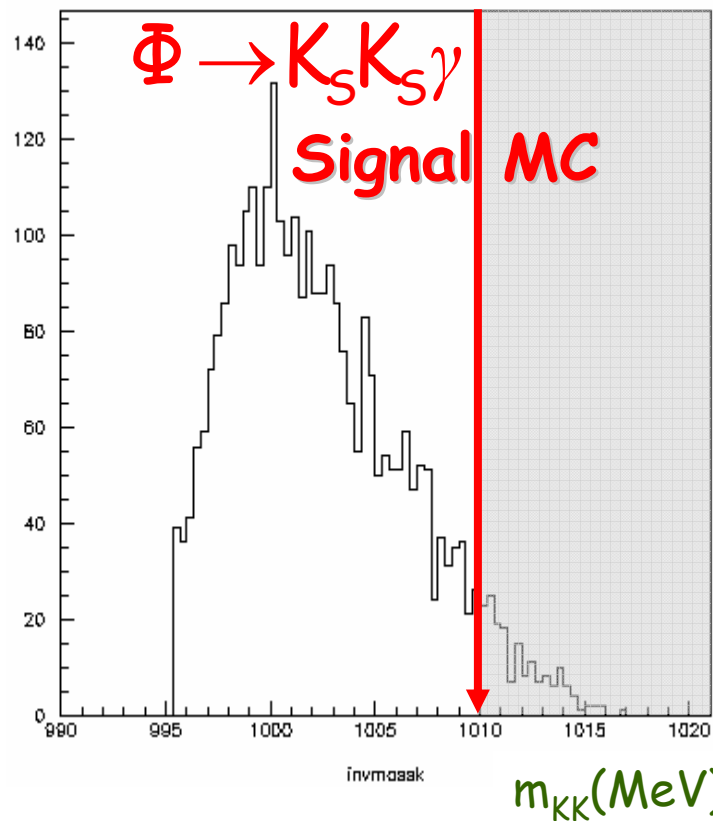


K_S invariant mass from $\pi^+\pi^-$ tracks: 4 MeV radius circle cut applied around K_S mass in $m(K_{S1})$ vs $m(K_{S2})$ plane



$K_S K_S$ invariant mass cut

f_0, a_0 mass as reconstructed from the two K_S tracks

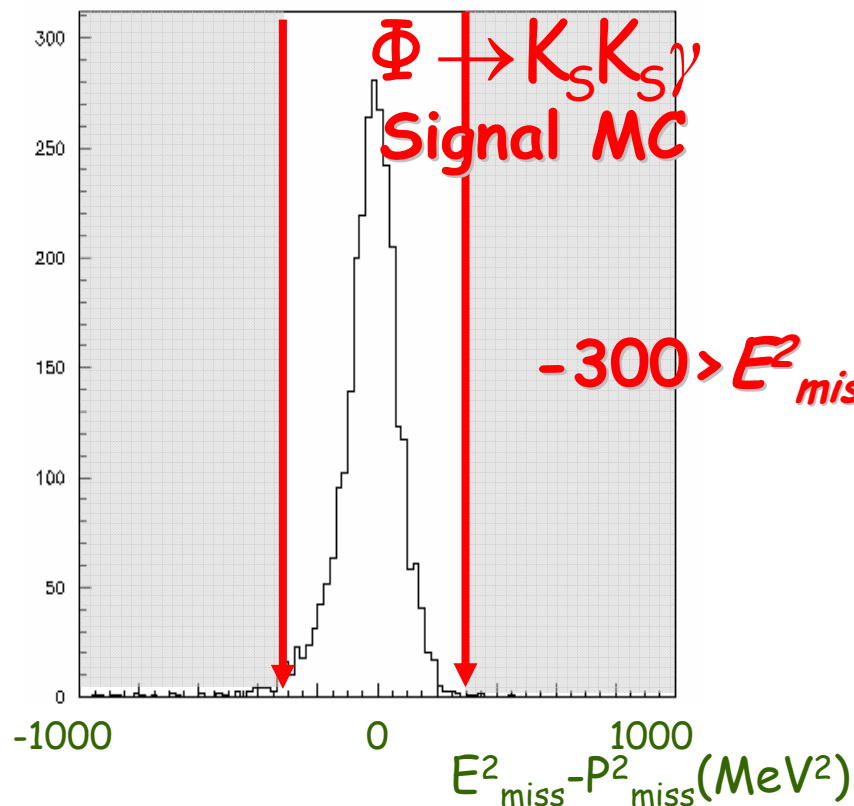


Cut: $m_{KK} < 1010 \text{ MeV}$



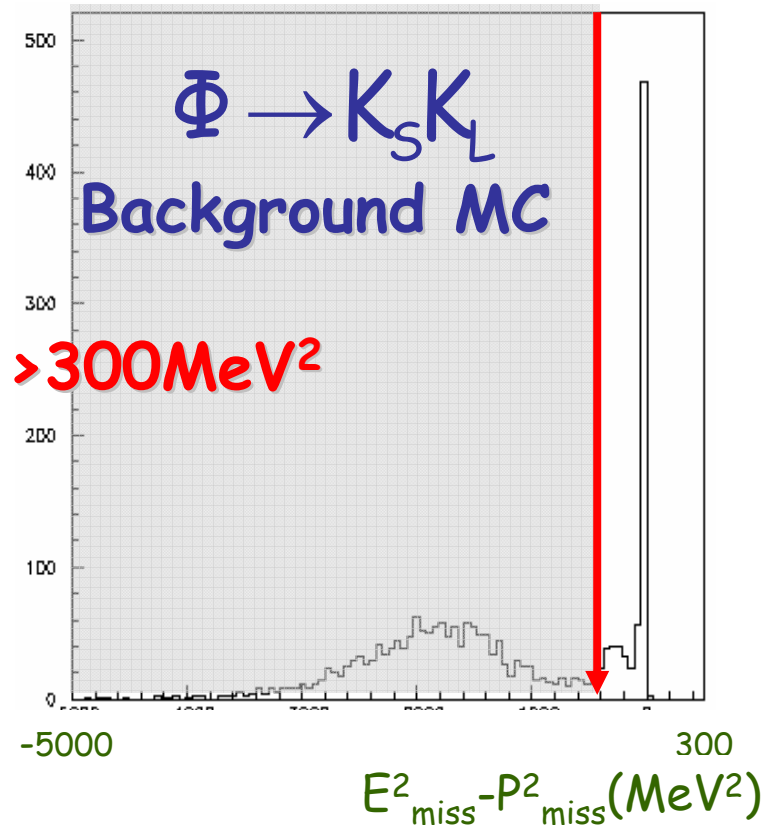
$E_{miss}^2 - P_{miss}^2$ "gammamass" cut

Using the 4-momentum conservation $\tilde{P}_\Phi - \tilde{P}_{K_1} - \tilde{P}_{K_2} = \tilde{P}_\gamma$ we obtain a variable $E_{miss}^2 - P_{miss}^2$ called "gammamass", which is zero for the signal, negative for channels like $K_S \rightarrow \pi e \nu$ (wrong K_S momentum reconstruction)



Cut:

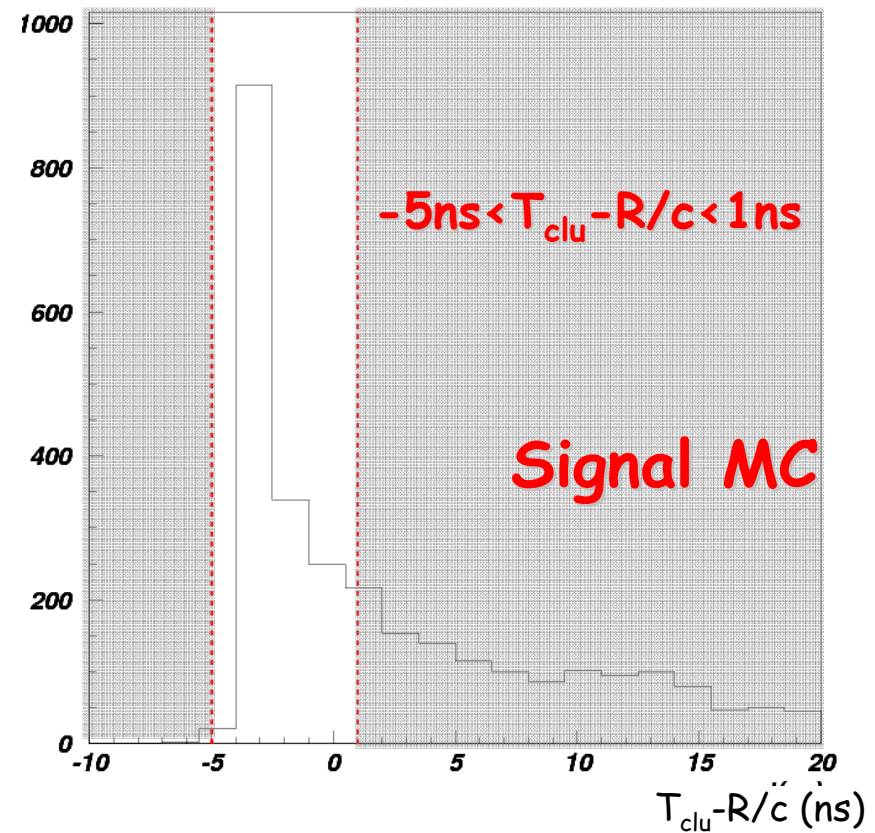
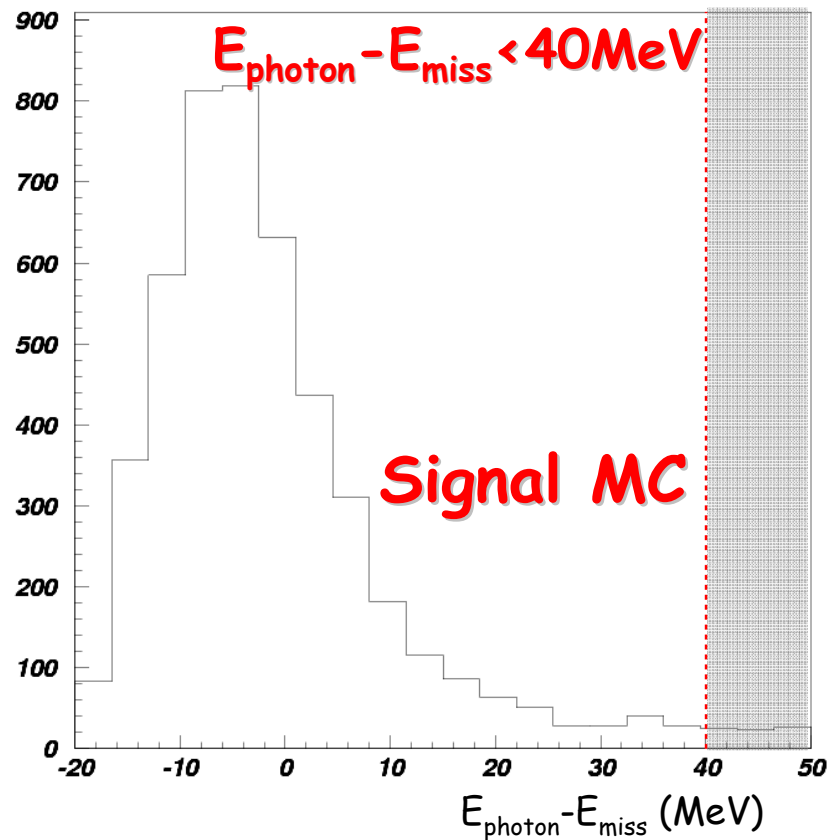
$$-300 > E_{miss}^2 - P_{miss}^2 > 300 \text{ MeV}^2$$





Photon request

- One cluster not associated with tracks
- Cluster energy compatible with missing momentum
- Photon in time window

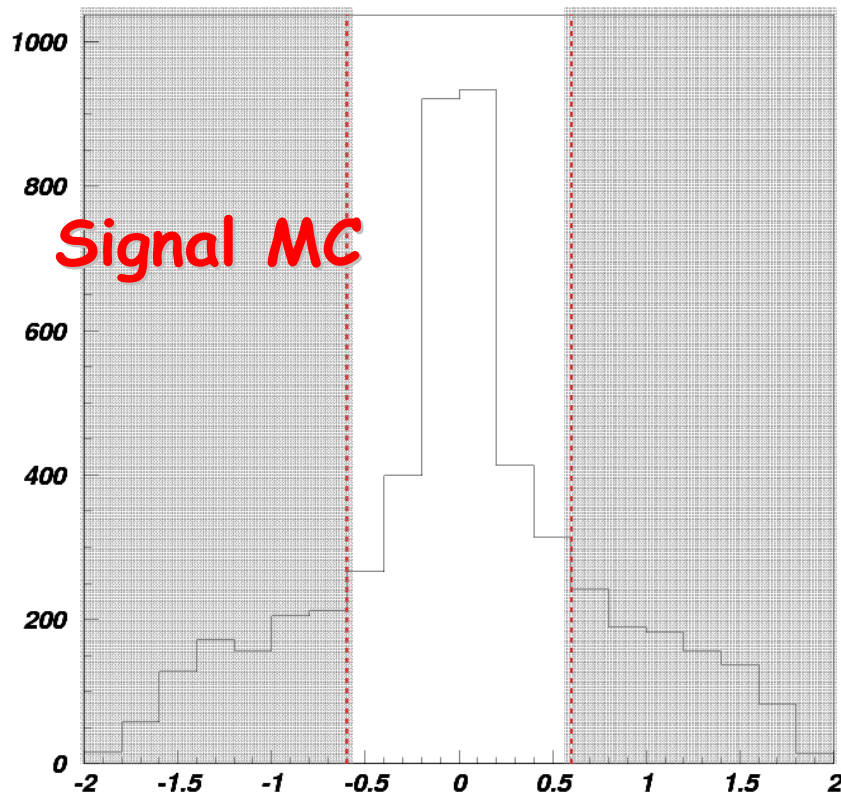


Photon direction

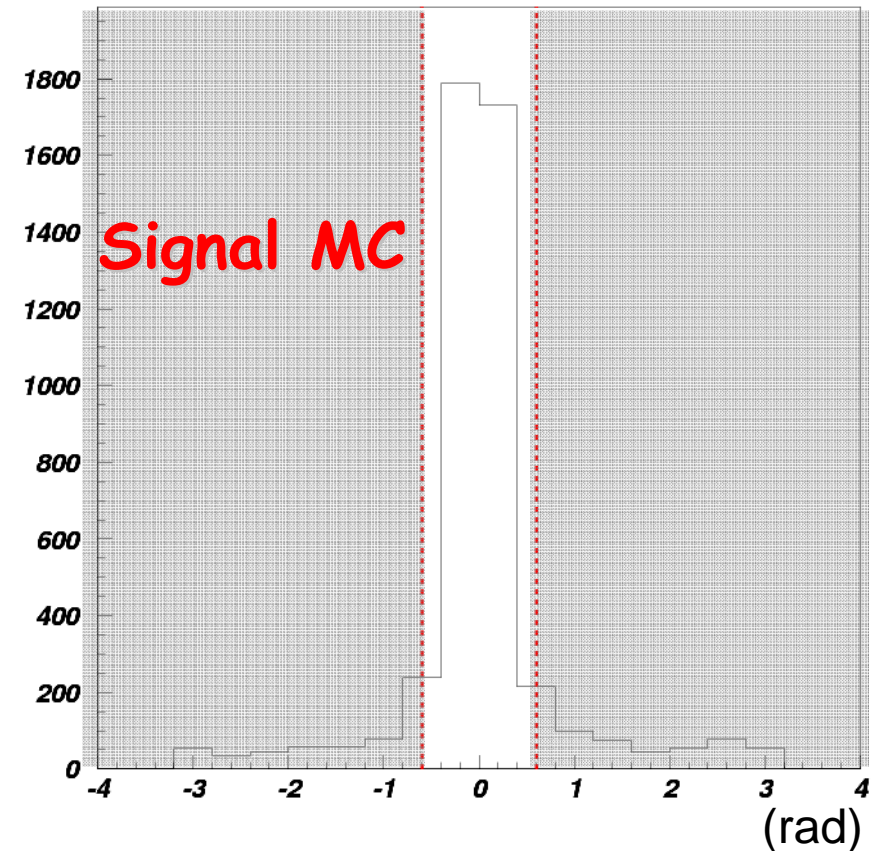


- “photon” direction compatible with $K_S K_S$ momentum

$$-0.6 < \cos(\theta_{\text{photon}}) - \cos(\theta_{\text{miss}}) < 0.6$$



$$-0.6 < \varphi_{\text{photon}} - \varphi_{\text{miss}} < 0.6$$



Kinematic cuts optimization



The optimization of the selection cuts has been performed looking only at signal and background MC's, and minimizing the quantity

No. events at 90% CL
efficiency

Here the quantity "No. events at 90% CL" is evaluated from the background surviving events, using Feldman Cousins method for sensitivity

(G. J. Feldman and R. D. Cousins, Phys. Rev. D57 (1998) 3873)

MC-DATA comparison



To check MC/DATA agreement use Signal and Background distributions in the $(E_{\text{miss}}^2 - P_{\text{miss}}^2, m_{KK})$ plane

- We chose 3 **sideband control samples**, made by those events which **did not survive the cuts** $m_{KK} < 1010 \text{ MeV}$ **and/or** $|(E_{\text{miss}}^2 - P_{\text{miss}}^2)| < 300 \text{ MeV}^2$
- For these events, we evaluated the **MC/DATA ratio** for m_{KK} and $(E_{\text{miss}}^2 - P_{\text{miss}}^2)$ distribution.
- Good agreement between MC and DATA in all sidebands
- Negligible effect of photons cuts on these ratios

Upper Limit calculation



- ❖ The upper limit is calculated as:

$$\text{B.R.}(\Phi \rightarrow K^0 \bar{K}^0 \gamma) < \frac{\text{UL}(\mu_{\text{sig}}) @ 90\% \text{CL}}{\int L dt \cdot \sigma(e^+ e^- \rightarrow \Phi) \cdot \frac{1}{2} \cdot \text{B.R.}(K_S \rightarrow \pi^+ \pi^-)^2 \cdot \varepsilon}$$

with: $\sigma(e^+ e^- \rightarrow \phi) = 3.09 \mu\text{b}$ $\int L dt = 1410 \text{pb}^{-1}$

$$\text{B.R.}(K_S \rightarrow \pi^+ \pi^-)^2 = (0.686)^2 \quad \varepsilon = 20.6\%$$

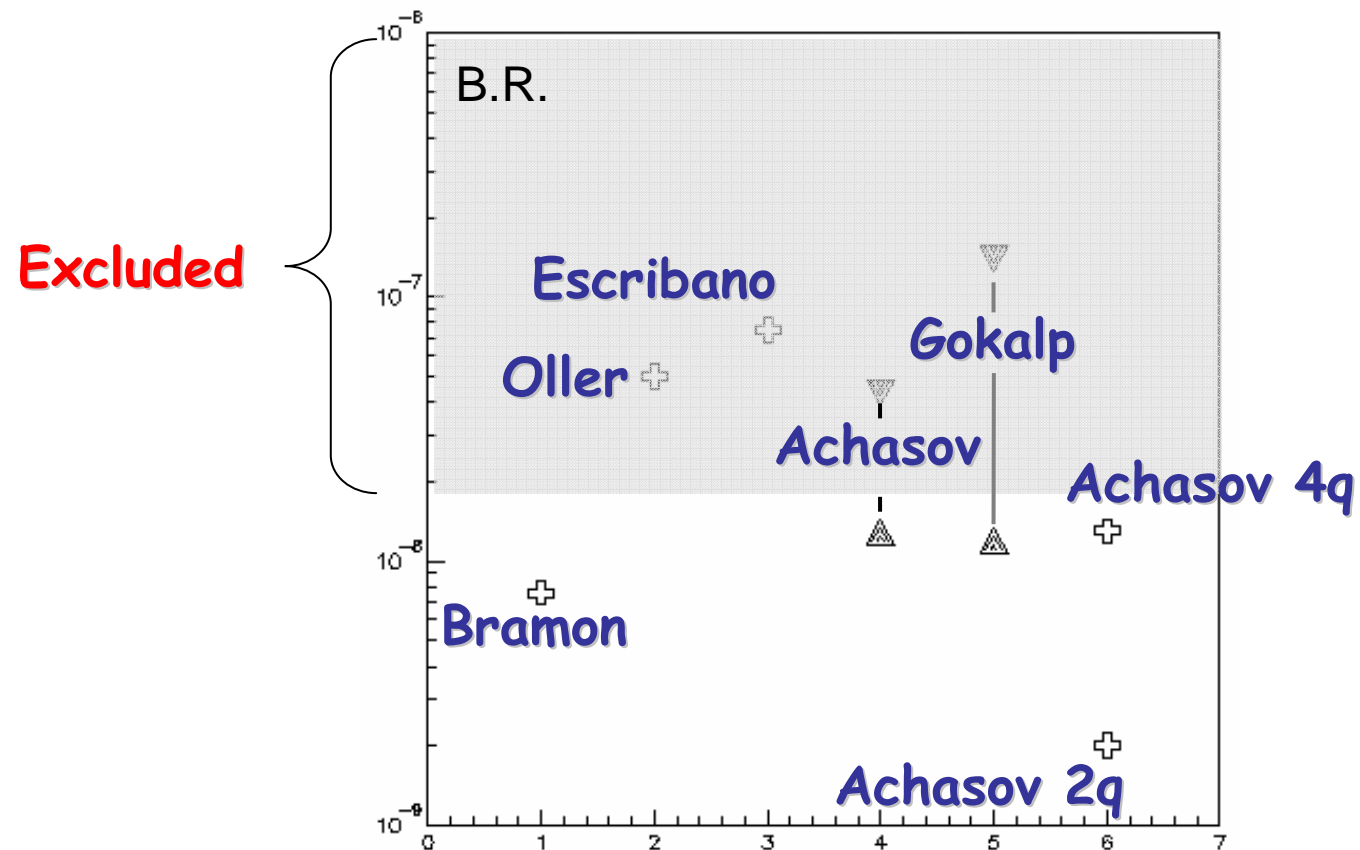
- ❖ With observed event $N_{\text{obs}}=1$, $\text{UL}(\mu_{\text{sig}})$ at 90% C.L. = 3.9 evaluated using a Poisson distribution and without background subtraction.
- ❖ Expected background events $N_{\text{bkg}}=0$

UL result vs theoretical predictions



Using 1410 pb^{-1} our preliminary result is:

$$\text{B.R.}(\phi \rightarrow (f_0 + a_0)\gamma \rightarrow K^0 \bar{K}^0 \gamma) < 1.8 \cdot 10^{-8} \text{ at 90\% C.L.}$$



Conclusion and perspectives



- ❖ The first U.L. on $B.R.(\phi \rightarrow (f_0 + a_0)\gamma \rightarrow K^0 \bar{K}^0 \gamma)$ has been set at $1.8 \cdot 10^{-8}$ at 90% C.L.
- ❖ Many theoretical models have been excluded
- ❖ Increase statistics by 50% from 2004 data taking
- ❖ Include background subtraction and systematic uncertainties in U.L. evaluation



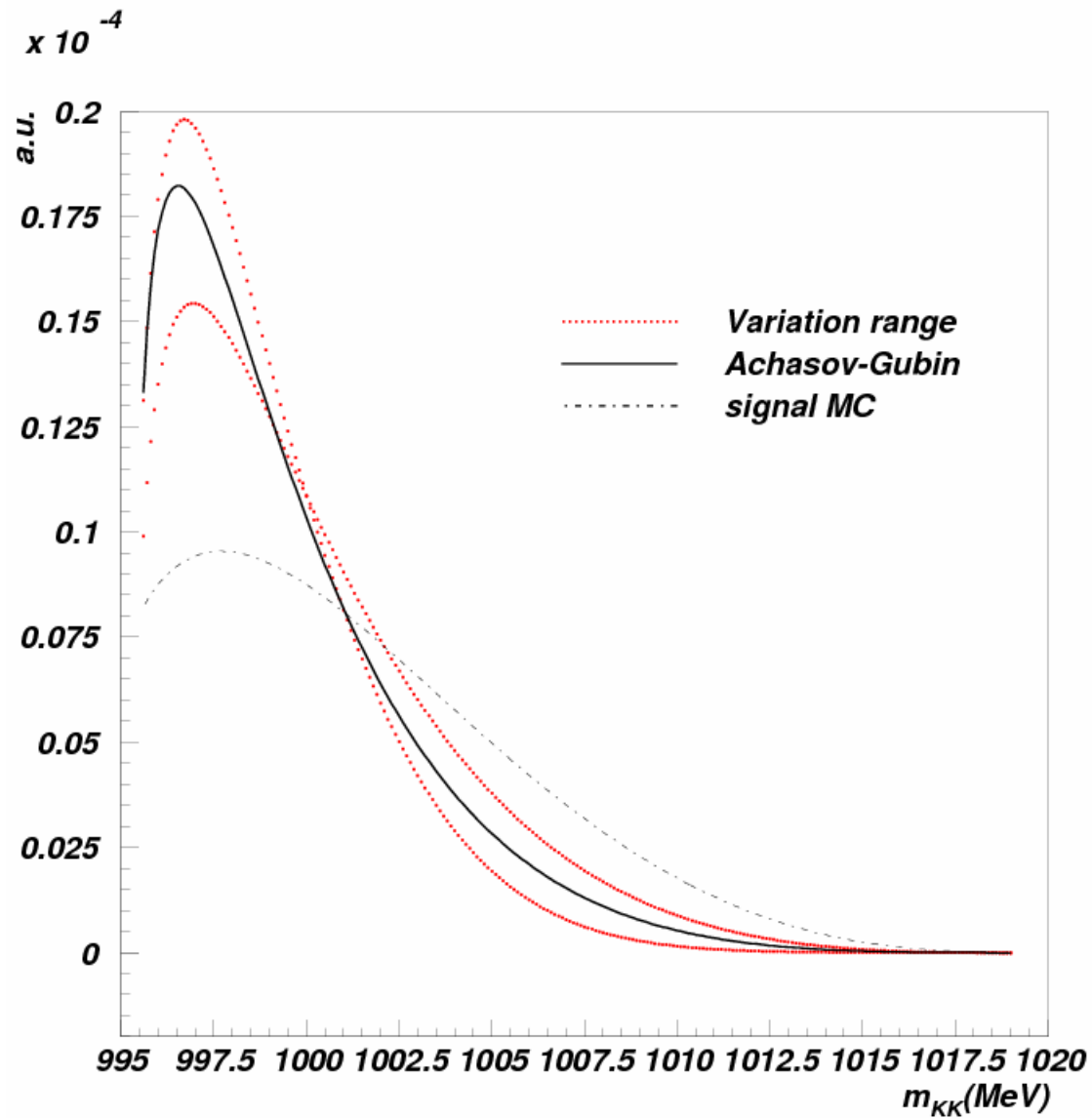
reach the sensitivity of $\sim 1 \cdot 10^{-8}$



Spares



Kaon-loop model vs us



#ev @ 90% c.l.

efficiency

vs. cuts choice

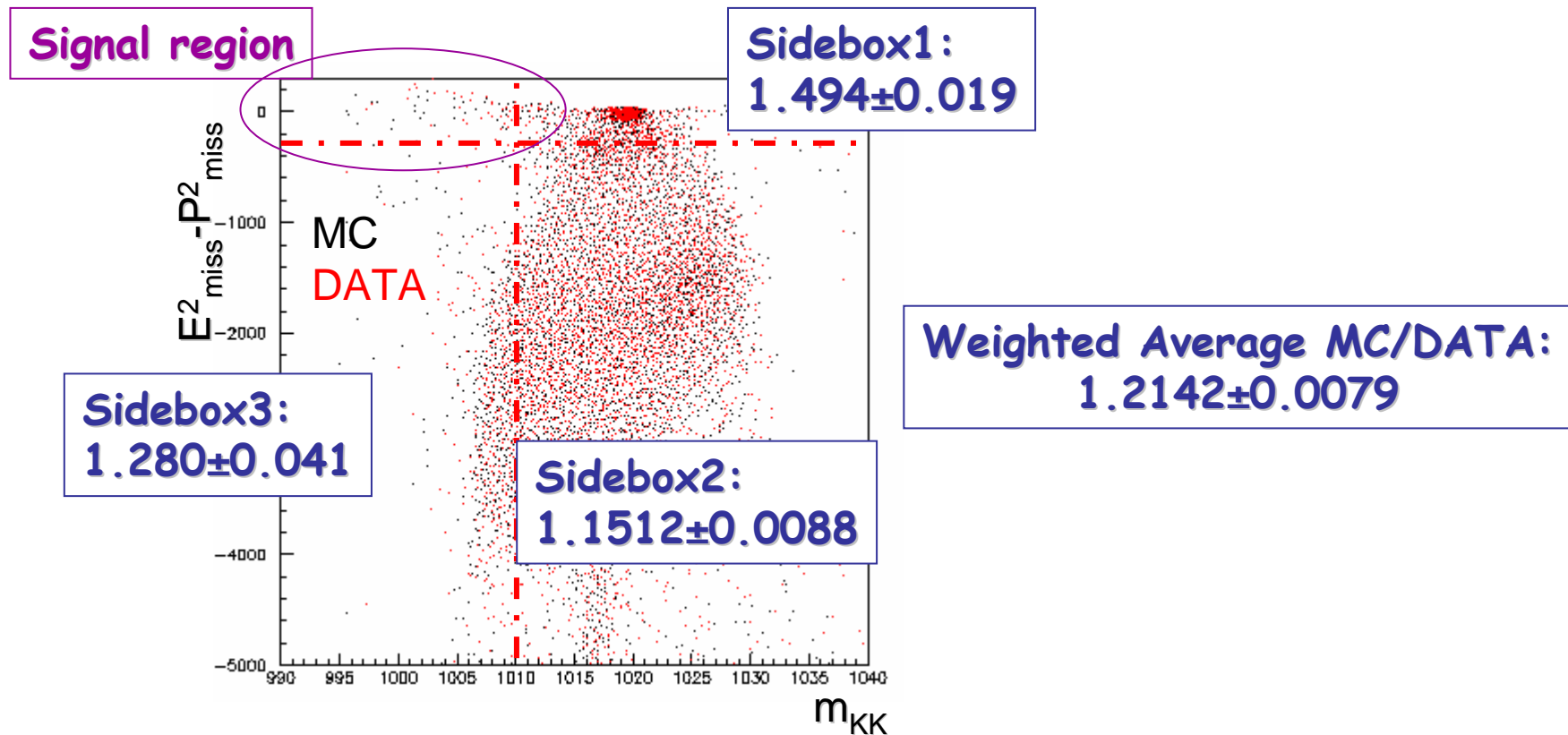


	<1005MeV	<1010MeV	<1015MeV
$\pm 100\text{MeV}^2$	Previous choice		35.5
$\pm 200\text{MeV}^2$	26.2	19.5	29.6
$\pm 300\text{MeV}^2$	23.2	18.0	
$\pm 400\text{MeV}^2$	22.5	18.2	31.2
$\pm 500\text{MeV}^2$		18.1	

MC/data ratios in sideboxes



- ❖ MC/data for each sidebox, without m_{KK} and $E_{miss}^2 - p_{miss}^2$ cuts :

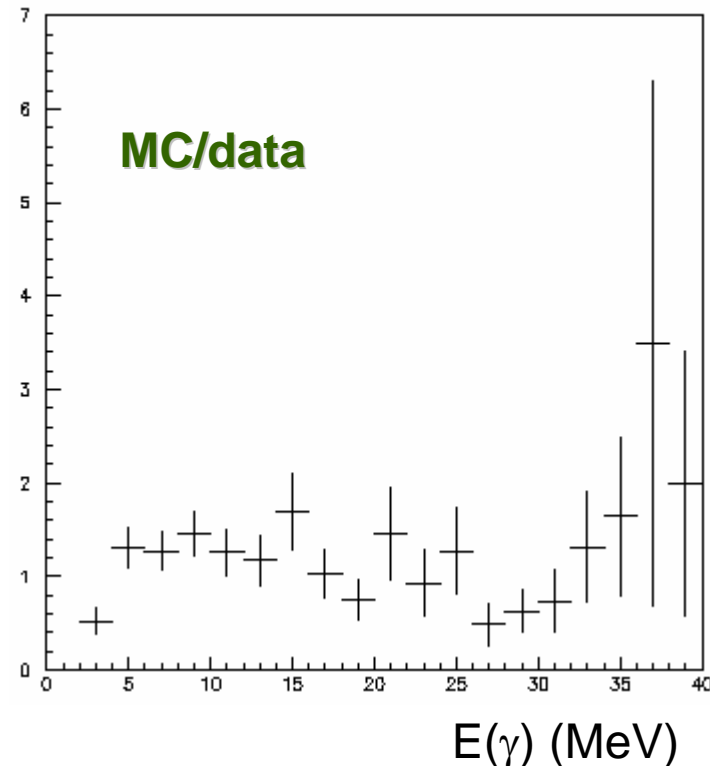
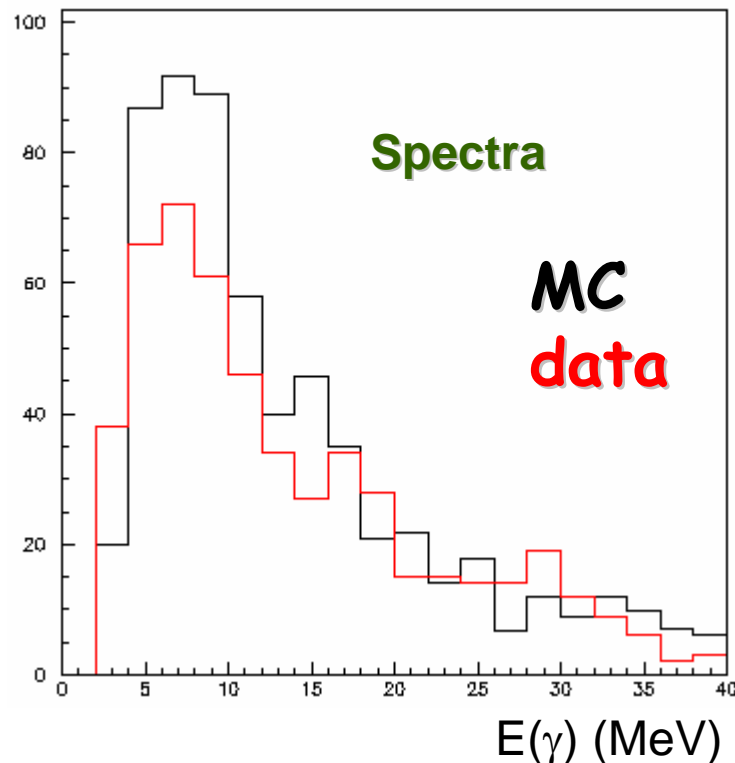


- ❖ Negligible effect of photons cuts on these ratios

EMC Cluster energy: MC vs data



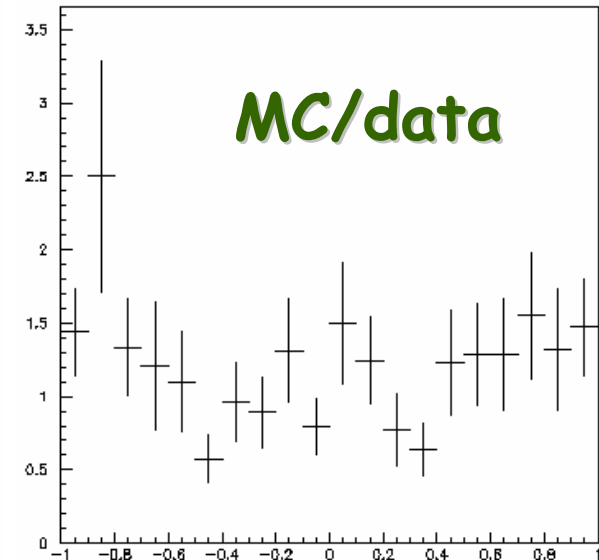
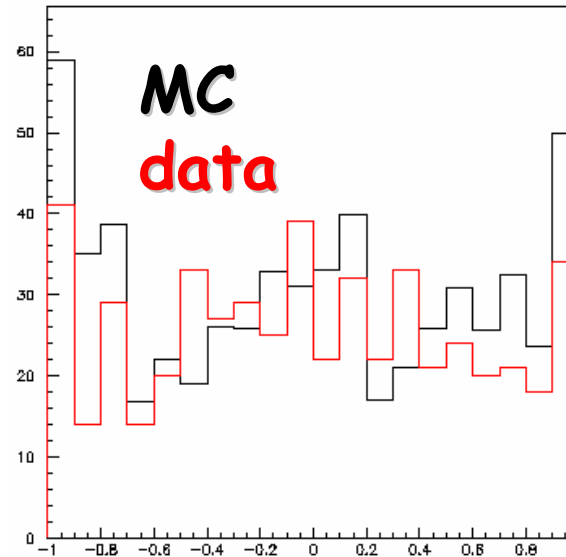
- MC-data agreement for clusters' **energy** and **angles** has been checked: these distributions are **plotted for events surviving "photon" cuts, but without applying all the kine cuts**



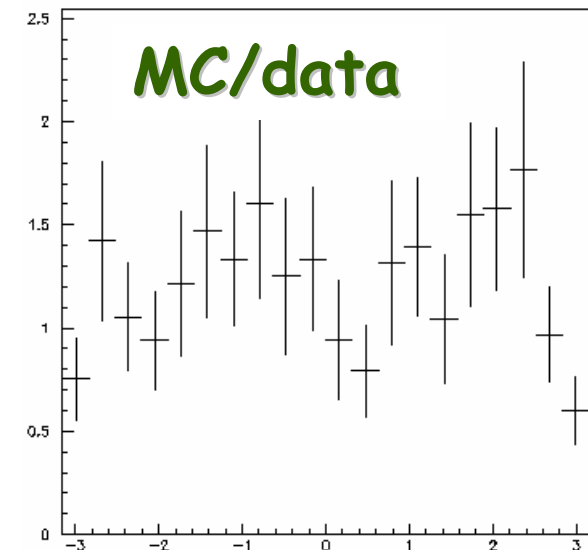
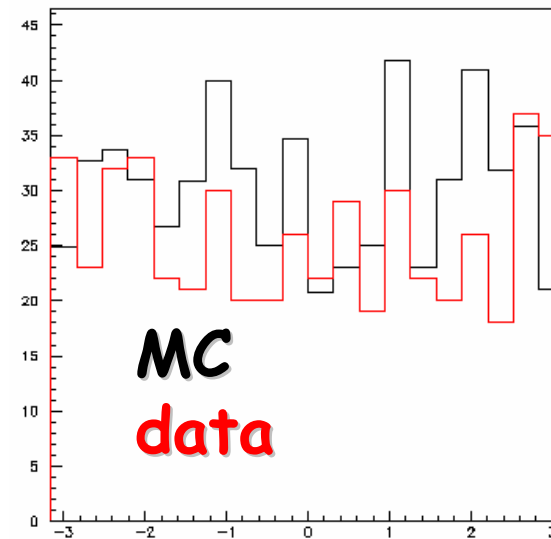
Cluster positions: MC vs data



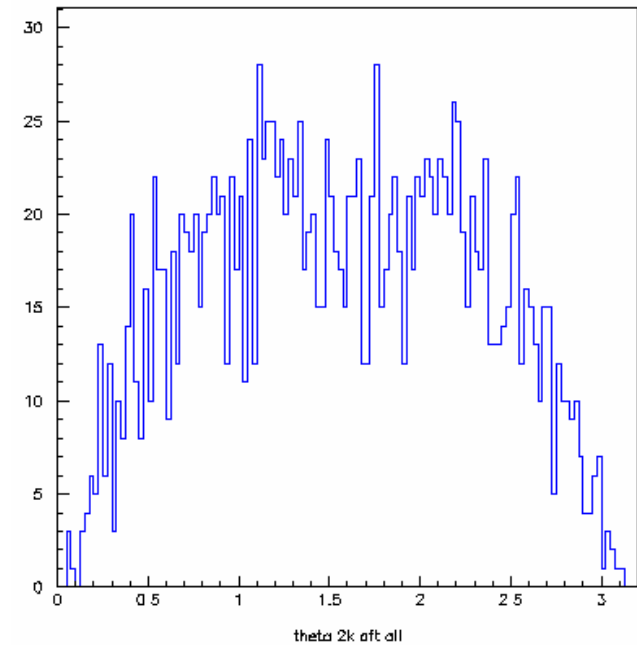
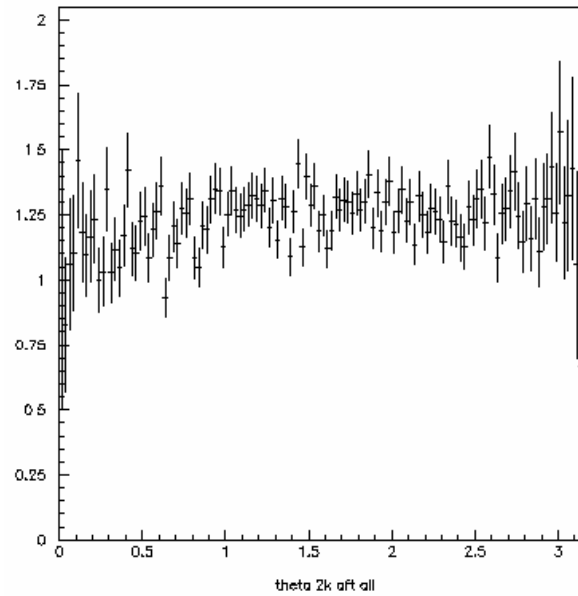
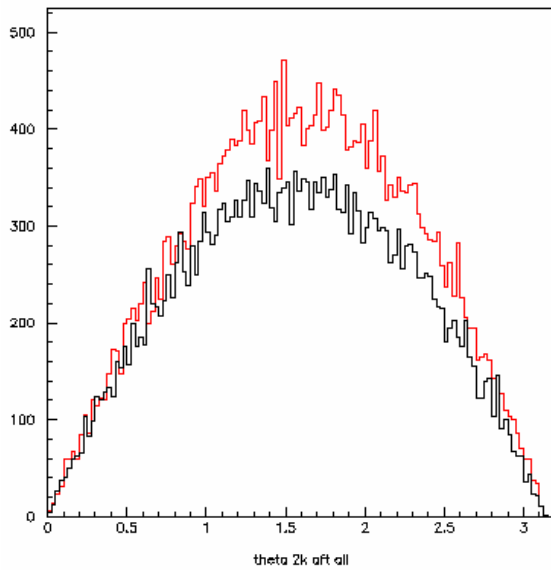
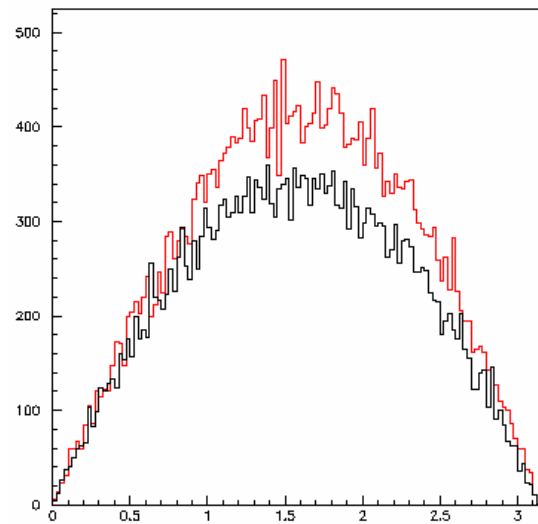
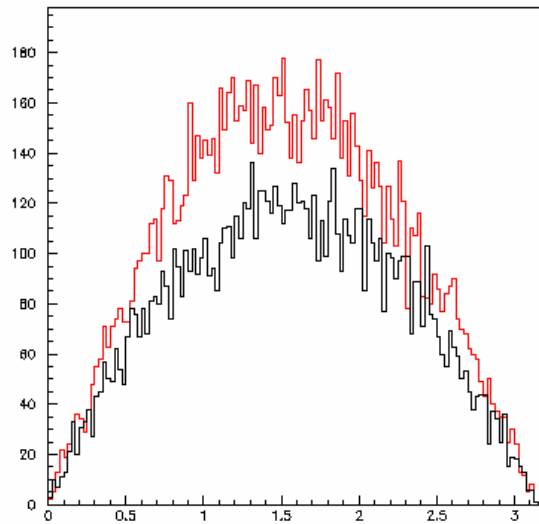
- Theta angle distributions:



- Phi angle distributions:



Theta2K before last kine



p_{K_S} before last kine

